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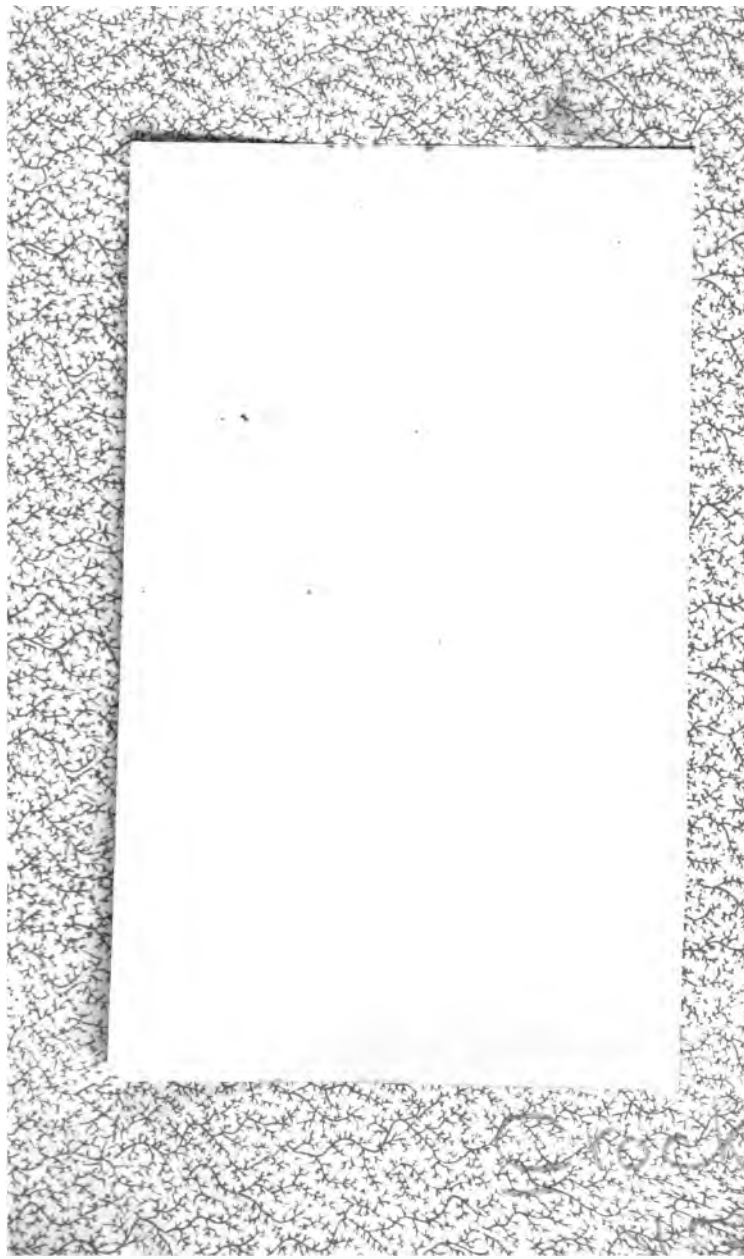

THE

PRACTICAL MANAGEMENT

OF

DYNAMOS AND MOTORS.

NEW YORK PUBLIC

BY

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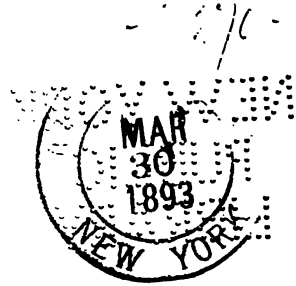

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PREFACE.

THE contents of this book appeared as a series of articles in the *Electrical Engineer* between September 1891 and May 1892. Its object is to give *simple* directions for the practical use and management of dynamos and motors.

The authors have taken special care to arrange the material so that the different subjects are treated separately and in the proper order, and the headings are printed in heavy type to facilitate ready reference to any subdivision.

The reader is recommended to familiarize himself at first with the plan and contents of the book, that he may be able to turn readily to any part of the book wanted when at work.

The authors design the present volume to be simply the ground-work of a larger and more elaborate treatment of the subject which they contemplate preparing and they will appreciate any suggestions.

NEW YORK, *May*, 1892.

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THE

PRACTICAL MANAGEMENT

OF

DYNAMOS AND MOTORS.

INTRODUCTION.

THE purpose of these articles is to set forth the more important facts which present themselves in the actual handling of dynamo-electric machines and electric motors, as a guide for those who use or study these machines. The authors do not claim for this treatment of the subject that it is anything more than a set of directions in which the various points are arranged under headings for convenience of reference.

The subjects considered are: Chapter I, General Principles of Dynamos and Motors; Chapter II, Directions for Selecting; Chapter III, Installing; Chapter IV, Starting; Chapter V, Running; Chapter VI, Stopping; and Chapter VII, Testing Dynamos and Motors; also Part II, Directions for Locating and Remedying Troubles in these machines.

Heretofore writers on the dynamo or motor have usually treated these machines entirely distinctly, and books or papers on the dynamo usually contain nothing about the motor, or merely consider it briefly in a few special chapters, and books on the motor only refer to the dynamo in-

cidentally. The authors have found that there is no necessity for this separation; in fact, nine out of ten statements which apply to the dynamo are equally applicable to the motor, and if the word machine is used instead of dynamo, the statement covers both and becomes doubly important and useful. Occasionally, of course, it is necessary to distinguish between the two machines, but, as a matter of fact, the difference in treatment required for dynamos and motors is often less than for different kinds of dynamos; for example, a shunt dynamo and series dynamo differ from one another much more than do a shunt dynamo and shunt motor.

Chapter I.

GENERAL PRINCIPLES OF DYNAMOS AND MOTORS.

Definitions.—*A dynamo-electric machine is a machine for converting mechanical energy into electrical energy;* in other words, *it generates electric current when driven by mechanical power.* The term dynamo-electric machine is so long that it is usually and unavoidably shortened into "dynamo," which has exactly the same meaning. The name "electric generator" or simply "generator" is often applied to the dynamo, especially when used to produce current for electric railway or other motors, but this distinction is merely for convenience. An alternating-current dynamo is commonly called an "alternator."

An electric motor is a machine for converting electrical energy into mechanical energy; in other words, *it produces mechanical power when supplied with an electric current.* An electric motor is usually called simply a motor, and although motor might mean anything producing motion, it is very rarely used in any other sense and is perfectly definite in connection with electrical matters.

Principles of Action.—The dynamo is based upon the discovery made by Faraday in 1831, that an electric current is generated in a conductor by moving it in a magnetic field. The electric motor works on the principle that a conductor carrying a current in a magnetic field tends to move. Thus it will be seen from the above statements that the dynamo and motor are exactly the reverse of each other in their action.

Similarity of Dynamos and Motors.—The two machines are, however, very similar in their construc-

tion. In fact, the same machine can be used for either purpose equally well. In practice there are sometimes slight differences between dynamos and motors, as will be explained further on, but these are not very important. Hence, as already stated in the introduction, the two machines will be treated as one, except where some distinction is specially stated.

General Form.—We have seen that both the dynamo and motor depend for their action upon the movement of conductors in magnetic fields. Now it has been found as a result of scientific experiment and practical experience during the 60 years since Faraday's discovery, that the best way to carry out this principle is to arrange the conductors in suitable form and rotate them between the poles of a magnet, or magnets. This rotating part is called the *armature* and the magnet is called the *field magnet.* In alternating-current dynamos this plan is sometimes reversed, the field magnets being made to rotate and the armature being fixed.

Armature.—This usually consists of an *armature core* of iron on which are wound or attached the conductors which carry the current. This core should be split up or *laminated*, that is, made of discs, tape or wire, of iron separated by paper, varnish or rust, instead of one solid piece; otherwise it will have useless currents generated in it which would waste the power of the machine. This core is almost always made either in the form of a *drum* or a *ring*, and hence we have these as the two principal types of armature.

Field Magnet.—This consists of one or more iron *cores* on which are wound the field *coils.* Attached to the field cores are the *pole-pieces* which form the magnetic field or space in which the armature revolves.

Chapter II.

DIRECTIONS FOR SELECTING DYNAMOS AND MOTORS.

The choice of a dynamo or motor will, of course, depend largely upon the circumstances in each particular instance. There are, however, certain general facts which apply to almost all cases.

Construction.—This should be of the most solid character and first-class in every respect, including material and workmanship, both of which should be of the best possible quality. All the parts should be of adequate size and strength to insure durability.

Finish.—What is called a fine finish on a machine is also very desirable, first, because it indicates good construction, and its absence indicates poor construction (there is no essential reason for this, but it seems to be a fact in most cases), and second, it usually causes a machine to receive much better treatment.

Simplicity.—The machine and all its parts should be as simple as possible, and any very peculiar or complicated part or attachment should be avoided. These are sometimes successful but should be well tried and proved before accepting.

Attention.—The amount of attention required by the machine should be small; for example, the brushes should be capable of being easily and securely adjusted, and the oiling devices should be effective and reliable, self-oiling bearings being very desirable. The screws, connections and other small parts should be arranged so that they are not liable to become loose, and the delicate parts should

not be particularly exposed or liable to injury. The machine should be made so as to be easily and thoroughly cleaned.

Handling.—The machine should be provided with rings or other means by which it can be easily lifted or moved without injury. It should be possible to take out the armature conveniently by removing one of the bearings.

Regulation.—Some form of regulator should be provided by which the E. M. F. or current of a dynamo or the speed of a motor can be reliably and accurately governed.

Armature.—This should turn very freely in the bearings, and should be perfectly balanced so as not to have any appreciable jar or vibration at full speed. There should be a uniform clearance of at least $\frac{1}{16}$ inch all around between the armature and pole-pieces. The armature should be capable of moving lengthwise in the bearings at least $\frac{1}{8}$ inch. It is not usually desirable to have the speed of an armature at its circumference more than 3,000 feet per minute. The ring-form of armature is especially suited to high voltage since the coils differing most in potential are at the greatest distance apart. A section of a ring armature can also be more easily rewound than in the case of a drum armature.

Capacity.—This should be ample in all cases. It is a very common mistake to underestimate the work required of a given machine, and, even if the machine has sufficient power at first, the demands upon it are apt to increase and finally overload it. No one is ever likely to regret choosing a dynamo or motor with a considerable margin of capacity, since these machines only consume power in proportion to the work they are doing. For example, a 30 h. p. machine would probably run with a 20 h. p. load more economically and satisfactorily than a 20 h. p. machine with same load.

Form.—The machine should be symmetrical, well proportioned, compact and solid in form. If it is either very tall or very flat it is usually inconvenient and clumsy. No part of the machine should project excessively, or be awkwardly formed or arranged. The large and heavy portions of the machine should be placed as low as possible to give great stability. For the same reason the shaft should not be high above the base, nor should it be so low that there is not ample room for the pulley or other attachment. A horizontal belt, for example, will sag and strike the floor if the pulley is very low.

Weight.—The common idea that it is desirable to have a very light dynamo or motor is a mistake when it is for stationary use. There is no advantage in a light machine for stationary work, and it has the disadvantages of being less strong, less durable and less steady in running. A sufficient weight to make the machine thoroughly substantial is obviously a great benefit.

Cost.—It is also a mistake to select a cheap machine, since both the materials and workmanship required in a high quality dynamo or motor cost more than in almost any other machine of the same size and weight.

The Various Kinds of Circuits on which dynamos and motors are commonly used, and the best type of machine in each case, is as in the tables on page 8.

These suggestions as to selecting a dynamo or motor may be followed when it is possible to make only a general examination of the machine, or even in cases where it is only possible to obtain a drawing or description of it. If it is desired to make a complete investigation of the machine, it is, of course, necessary to make a thorough test and measure exactly its various constants. This can be done as completely as may be required by following the Directions for Testing, which are given in another chapter.

A satisfactory test cannot usually be made, however, until

after the machine is set up in place; and, moreover, it is not generally necessary if the machine is obtained from a reputable source.

CONSTANT POTENTIAL.

(*Circuits on which potential or voltage is kept constant, machines, lamps, etc., run in parallel.*)

Circuits intended for—	Potential.	Dynamo should be—	Motor should be—
Incandescent lighting.....	110 volts (2-wire sys.) 220 volts (3-wire sys.)	Plain shunt or compound wound.	Plain shunt wound.
Electric railway. Power circuits....	500 volts.	Plain shunt or compound wound.	Series wound for railway. Shunt wound for stationary.

CONSTANT CURRENT.

(*Circuits on which current or amperes are kept constant, machines, lamps, etc., run in series.*)

Circuits intended for—	Current in Amperes.	Dynamo should be—	Motor should be—
Arc lighting.... wer circuits..	6.8 9.5 or 18	Series wound with current regulator.	Series wound with speed regulator.

Chapter III.

DIRECTIONS FOR INSTALLING DYNAMOS AND MOTORS.

Setting up.—The place selected for a dynamo or motor should be dry, clean, cool, away from all pipes if possible, where the machine is in plain sight and is easily accessible and taken care of. Avoid particularly any dusty, wet or hot location. Any place near which grinding, filing, turning or similar work is likely to be done, is very undesirable for a dynamo or motor, as the dust and chips produced are liable to injure the bearings, commutator and insulation of the machine. A firm and level foundation should be provided in any case, and larger machines of 20 h. p. or more should be set on solid stone, brick or timber foundations. It is well, particularly in the case of high-voltage machines, to have them placed upon an insulating base-frame of wood, the pores of which should be filled with paraffine or well varnished to keep out moisture. If a wooden belt-tightening base is used this will answer the purpose, but if iron tracks are used they should be placed on a wooden base-frame. Fig. 1.

In unpacking and putting the machines together the greatest possible care should be used in *avoiding the least injury to any part*, in *scrupulously cleaning each part* and in *putting the parts together in exactly the right way.* This care is particularly important with regard to the shaft, bearings, magnetic joints and electrical connections from which every particle of grit, dust, chips of metal, &c., should be removed. It is very desirable to have machinery put together by a person thoroughly familiar with its construction, and in the absence of such a person no one should attempt it without at least a drawing or photograph

of the complete machine as a guide. An exception may be made to this rule if the machine is very simple and the way to put it together is perfectly obvious, but in no event should the installation or management of machinery be left to guess-work. The armature should be handled with the greatest possible care in order to avoid injury to the wires and their insulation, as well as to the commutator and shaft. Handle and support the armature as far as possible by the shaft and avoid any strain on the armature body or commutator. If it is necessary to lay the armature on the ground, interpose a pad of cloth, but it is much better to

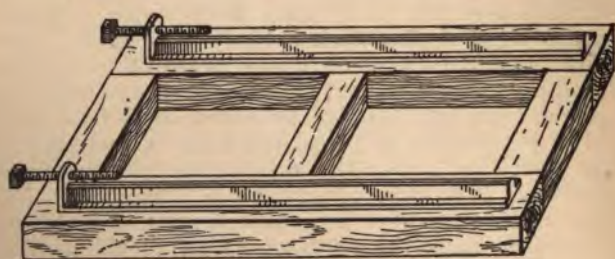


FIG. 1.—BASE FRAME.

rest the shaft on two wooden horses or other supports. A convenient form of sling for handling armatures is shown in Fig. 2.

Pulleys.—A dynamo or motor is usually furnished by the maker with a pulley suited to it. In the case of a dynamo, do not use a smaller pulley, and with a motor do not use a larger one without consulting a competent electrical engineer. The size of pulley required on the other hine or counter-shaft to which the given machine is to nnected is found by multiplying the revolutions per e of the dynamo or motor by the diameter of its

pulley expressed in inches and dividing by the revolutions per minute required of the other shaft, which gives diameter of pulley in inches. The proper speed for a dynamo or motor should always be obtained from its manufacturers, and this speed should not be departed from without their

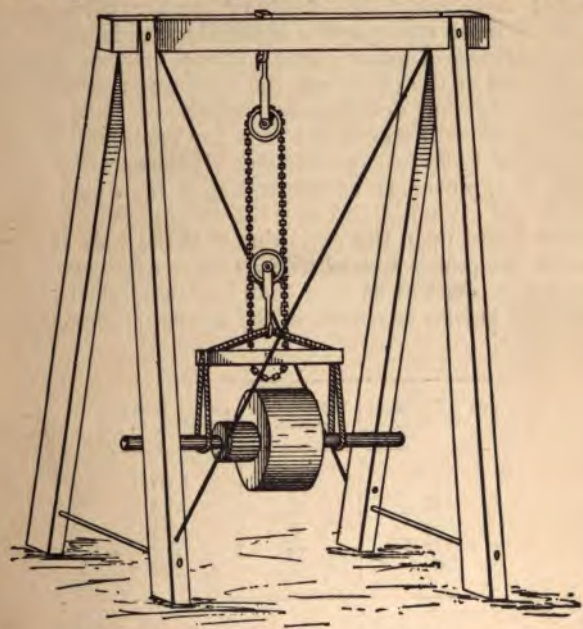


FIG. 2.—SLING FOR HANDLING ARMATURE.

approval. A simple rule for determining the sizes and speeds in any belt or gear transmission is that the speed of one pulley or gear wheel multiplied by its diameter must be equal to the speed of the other multiplied by its diameter. An allowance should be made of one or two per cent. loss of speed in the driven pulley owing to the slip of the

belt. In fact, the usual result is that the speed actually obtained in practice is less than is expected and this often makes a change of pulleys necessary.

Belting.—The kind of belting selected is somewhat a matter of taste but "light double" leather belting is applicable to most cases and is generally satisfactory. The width of belting is usually made about half an inch less than the face of the pulley on the dynamo or motor. The common rule for determining width of belt is that "single" belt will transmit 1 h. p. for each inch in width at a speed of 1,000 feet per minute. If the speed is greater or less, the power is correspondingly increased or decreased.

This is based upon the condition that the belt is in contact with the pulley around half its circumference or 180°. If the arc of contact is less than half a circle the power transmitted is less, as shown in the accompanying table:

Arc of contact of belt.	Fraction of circle.	Power transmitted, *C*.
180°	½	1.00
157½	7/16	.92
135	3/8	.84
112½	5/16	.76
90	¼	.64

The complete formula is, therefore, H. P. $= \frac{w \times s \times c}{1000}$

That is, the horse power transmitted by a belt is equal to width of belt in inches (w) multiplied by the speed of in feet per minute (s) and by the figure depending the arc of contact (c) and divided by 1000. For e, a belt six inches wide traveling at 1,500 feet per

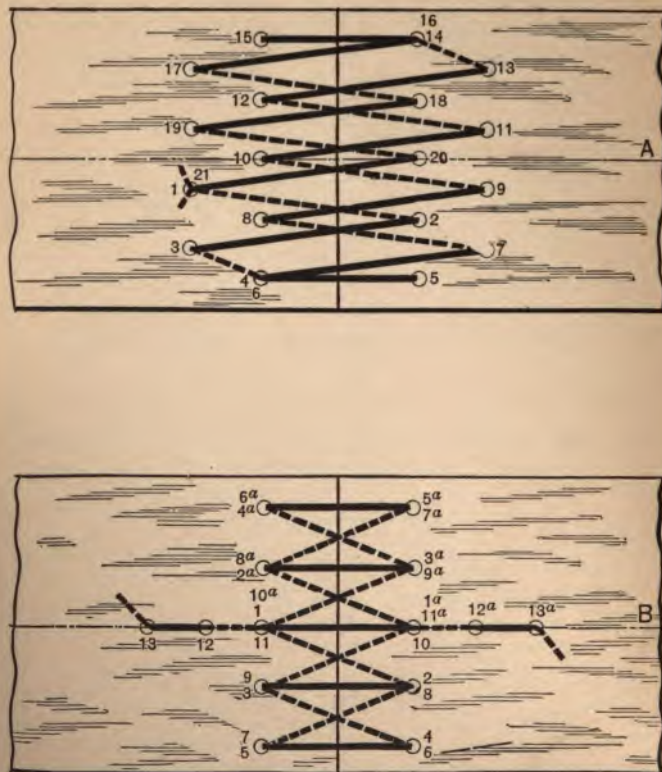


Fig. 3

METHOD OF LACING A BELT.

The smooth side of the leather of the belt goes against the pulley. The ed lines represent the lacing on the side away from pulley.

To face page 13.

minute and touching three-eighths of the circumference of the pulley will transmit:

$$\frac{6 \times 1500 \times .84}{1000} = \frac{7560}{1000} = 7.56 \text{ h. p.}$$

"Double" belting is expected to transmit one and one-half, and "light double" one and one-quarter times, as much power as "single" belting, of which 75 sq. ft. per minute transmits one h. p.

The smooth side of a belt should be run against the pulley, as it transmits more power and wears better. An endless belt should be used for dynamos and motors, since they usually run at high speeds. If an endless belt is not used, the joint should be very carefully laced so as to make it as straight and smooth as possible. In lacing belts there must always be as many stitches of the lacer *slanting* to the left as there are to the right. Otherwise the ends of the belt will shift sidewise, owing to the unequal strain, and the projecting corners will catch on something. Two good ways of doing this are shown in Fig. 3. In plan A two rows of oval holes should be made with a punch as indicated. The nearest hole should be three-quarters inch from the side, and the first row seven-eighths inch from the end, and the second row $1\frac{3}{4}$ inches from the end of the belt. In large belts these distances should be a little greater. A regular belt lacing (a strong, pliable strip of leather) should be used, beginning at hole No. 1 and passing consecutively through all the holes as numbered.

In plan B the holes are all made in a row. This plan has the advantage of making the lacers lie parallel with the motion on the pulley side. The lacing is doubled to find its middle, and the two ends are passed through the two holes marked "1" and "1A," precisely as in lacing a shoe. The two ends are then passed successively through the two series of holes in the order in which they are numbered, 2, 3, 4, etc., and 2A, 3A, 4A, etc., finishing at 13 and 13A,

which are additional holes for fastening the ends of the lacer.

A six-inch belt should have seven holes on each part; other widths in proportion. Be very careful to measure correctly the length of belt required, as it is very awkward to have it too short or even too long if it be an endless belt. If the machine has a belt-tightener, measure for belt when position of tightener makes belt the *shortest*, in order to allow for stretch, which is considerable in some belts.

Avoid short or vertical belts, as they are much more apt to slip than long or horizontal ones. If it is absolutely necessary to connect pulleys at different levels, make the belt as nearly horizontal as possible. The distance between the centres of two belt-connected pulleys should be at least three times the diameter of the larger pulley, and it may well be four times if the space permits.

Make belt just tight enough to avoid slipping without straining the shaft or bearings. A new belt will not carry as much power as one which has been properly used for a few months.

The dynamo or motor shaft and the shaft to which it is to be belted should be placed exactly parallel and the centres of the two pulleys should be exactly opposite each other in a straight line perpendicular to the shafts. The machine should then be turned slowly by hand to see if the belt tends to run to one side of pulley, in which case the machine should be slightly moved until the belt runs in the middle of the pulleys and does not tend to work to one side.

Rubber belt has 50% more adhesion than leather. Rubber and canvas stretch continuously. For new leather allow ⅛ inch per foot for stretching.

Belts "creep" over pulley or loose speed about 2%. Hence in determining size of pulleys when speed must be ...rate, arrange them to make speed *figure out* 2% too high.

...trical Connections.—As already stated these should ... carefully cleaned, and this may well be car... ...e extent of rubbing them vigorously with clean

cloth or chamois skin. Any of the metal surfaces used in making electrical contacts which are tarnished should be brightened with fine sandpaper or by scraping them, but all sand, metallic particles, etc., must be carefully removed afterwards. Particles of sand or dirt are often left accidentally between surfaces which should be in perfect contact.

Wiring.—It is very desirable to have a thoroughly competent lineman or electrician to connect a dynamo or motor to the circuit, see that everything is properly arranged and start the machine the first time.

FIG. 4.—WIRES CARRIED ON PORCELAIN.

The connections should all be made in a substantial and permanent manner. Good quality of insulated wire should be used and should be properly arranged and laid.

Temporary, loose or poorly insulated wires or connections are very objectionable. All circuits exposed to moisture should be supported on glass, porcelain or other waterproof insulators. Circuits of over 250 volts even where not exposed to moisture should also preferably be carried on porcelain or similar insulators, as shown in Fig. 4, and out of reach if possible, and the best insulated wire should be used.

Low-voltage circuits of 230 volts or under may be run in wooden moulding or cleats where entirely unexposed to

moisture. Where wires pass through walls, floors, over pipes or are otherwise liable to injury they should be protected by hard-rubber tubing or other equally good covering. No wire smaller than No. 8 B. & S. gauge should be used for the arc current of 10 amperes, and other wires should be in proportion; that is, they should have from 800 to 1,200 circular mils per ampere. The former figure (800) is for small wires, in cool places; the latter figure (1,200) is for wires carrying heavy currents or high voltage and wires in hot places such as ceilings of kitchens, etc. No wire smaller than No. 16 should ever be laid to

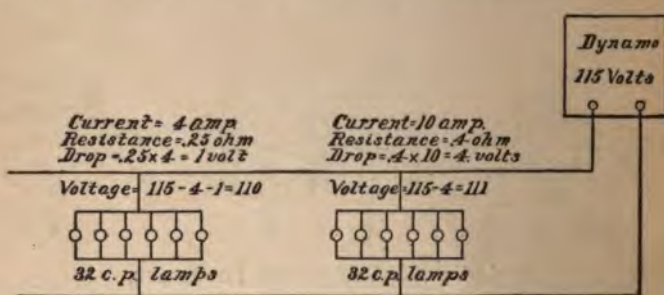


FIG. 5.—"DROP" ON BRANCHING CIRCUITS.

carry any current from a dynamo (smaller wires may be used for primary battery currents) no matter how small the current may be.

The above sizes of wire are rather larger than are generally given but it is wise to have an ample margin. Failure to allow a proper margin or factor of safety has been the cause of most of the troubles in all branches of electrical work.

In addition to the above allowances for current capacity or the ability of wires to carry the current without overheating, it is also necessary to consider the fall of potential

or "drop" on wires. This loss ought not to exceed 5 per cent. in isolated plants, 10 per cent. in central station systems, and about 20 per cent. in long-distance transmission. That is to say, the voltage at the most remote point on the system should not fall below the voltage at the dynamo by

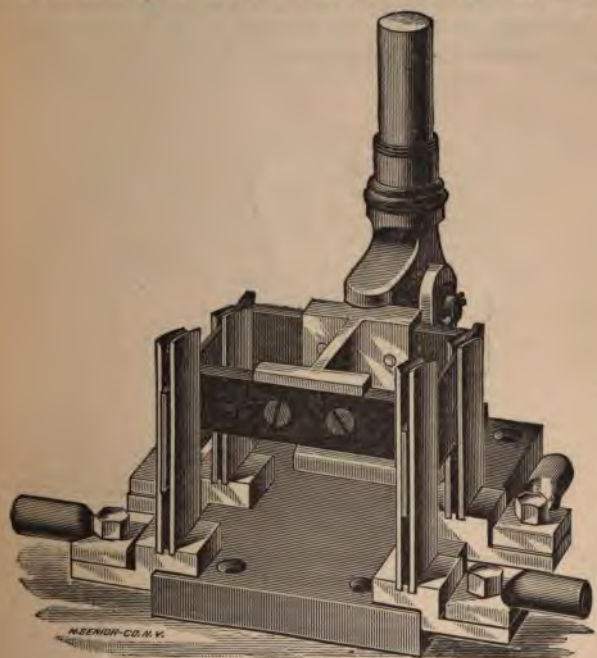


FIG. 6.—DOUBLE-POLE QUICK-BREAK SWITCH.

more than these percentages. A "wiring table" is given at the end of this work for determining the size of wire required in various cases. A simple rule derived from Ohm's law applicable to all cases is, that the lost voltage obtained

by multiplying the current in amperes at full load by the total resistance of the circuit in ohms must not be more than the given percentage of the voltage at the generator.

In the case of a branching circuit, shown in Fig. 5, or other case where the current is not the same throughout, the separate parts should be treated separately as indicated in the diagram. This calculation applies particularly to motors which are often put at the end of a long circuit or branch.

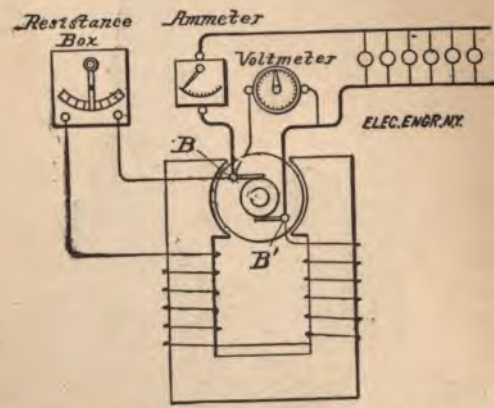


FIG. 7.—SHUNT DYNAMO ON CONSTANT POTENTIAL CIRCUIT WITH LAMPS IN PARALLEL.

Switches and Cut-Outs.—The bases of all switches, cut-outs, etc., should be of slate, porcelain or other fire-proof, non-porous, insulating material. On all constant-potential or multiple arc circuits, double-pole fusible cut-outs should be put where each branch starts. On all constant-current or arc circuits, double-pole cut-out switches should be put where the circuit enters any building and

also near any motor or group of lamps on such circuits. All high-voltage circuits and any low-voltage circuit carrying more than three amperes should be controlled by double-pole switches or cut-outs which entirely disconnect both sides of the circuit, and they should also preferably have a "quick break," especially with direct currents.

The exceptions to this rule are, first, constant-potential dynamos which usually have single-pole knife switches, the

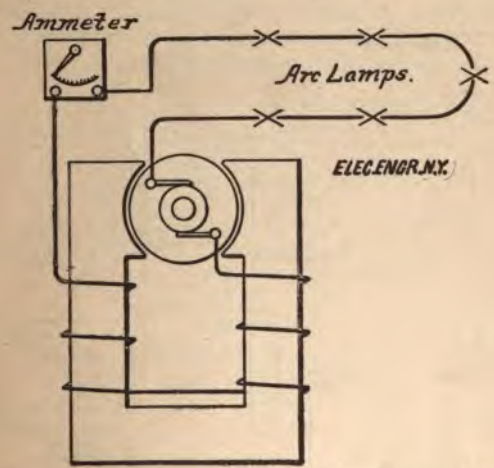


FIG. 8.—SERIES DYNAMO ON CONSTANT CURRENT CIRCUIT WITH LAMPS IN SERIES.

other pole being permanently connected to the circuit; and second, constant-potential motors which generally have single-pole switches on the starting boxes, the other pole being always connected to the circuit. In the latter case, however, it is recommended to also put a double-pole quick-break switch in the circuit, as shown in Fig. 6.

Diagrams of Connections are given in each important case to show the actual connections which are necessary. But when a machine is to be "connected up" a competent electrical engineer should be consulted or an exact diagram should be obtained from the maker of the machine, as its connections may be peculiar and cause serious trouble. Diagrams merely represent the path of

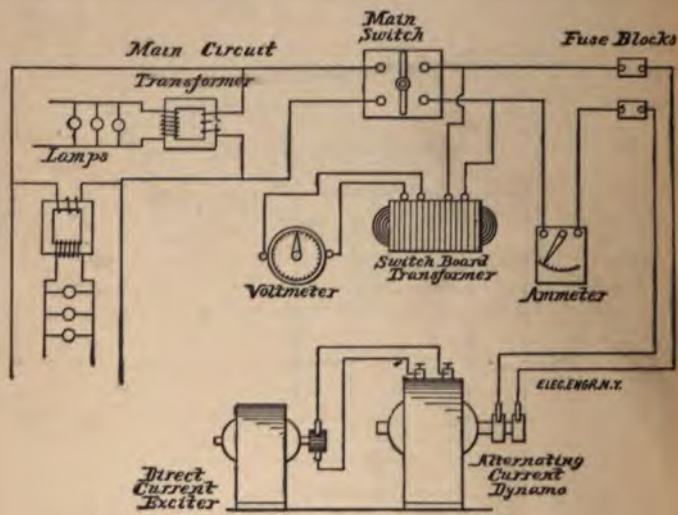


FIG. 9.—ALTERNATING CURRENT PLANT.

the wires in the simplest way, the important thing in electrical connections being *which* parts or wires are connected, not *how* they are connected. Whether the path be straight or crooked, vertical or horizontal, etc., is of no consequence. Diagrams of the three most important cases of dynamo connections are here given. The other diagrams of dynamos and motor connections are given hereafter.

Shunt Dynamo on Constant-Potential Circuit is represented in Fig. 7 with the necessary connections. The brushes B and B are connected to the two conductors forming the main circuit, also to the field magnet coils *through* a resistance box to regulate the strength of current and therefore the magnetism in the field. A voltmeter is also connected to the two brushes or main conductors to measure the voltage or electrical pressure between them. One of the main conductors is connected to an amperemeter which measures the total current on the main circuit. The lamps are connected in parallel between the main conductors or branches from them.

Series Dynamo on Constant-Current Circuit.—The connections in this case (Fig. 8) are extremely simple, the armature, field coils, amperemeter, main circuit and lamps, all being connected in one series.

Alternating-Current Plant.—The proper connections in this case are shown in Fig. 9, in which the names of the different parts of the plant are given and which therefore requires no explanation.

The diagrams of connections of all cases of *dynamos coupled together* and of *electric motors* are given in the chapter on Starting where they are required to explain the proper steps.

Chapter IV.

DIRECTIONS FOR STARTING DYNAMOS AND MOTORS.

General.—Make sure that the machine is clean throughout, especially the commutator, brushes, electrical connections, etc. Remove any metal dust, as it is very likely to make a ground or short-circuit.

Examine the entire machine carefully and see that there are no screws or other parts that are loose or out of place. See that the oil cups have a sufficient supply of oil, and that the passages for the oil are clean and the feed is at the proper rate. In the case of self-oiling bearings see that the rings or other means for carrying the oil work

See that the belt is in place and has the proper

If it is the first time the machine is started it be turned a few times by hand, or very slowly, in see if the shaft revolves easily and belt runs in of pulleys.

rushes should now be carefully examined and ad- o make good contact with the commutator and at per point, the switches connecting the machine ircuit being left open. The machine should then ed with care and brought up to full speed gradu- possible, and in any case the person who starts a dynamo or motor should closely watch the ma- and everything connected with it and be ready to in- shut down and stop it (and throw it out of circuit is connected) if the least thing seems to be wrong, ould then be sure to find out and correct the trouble starting again. (See "Locating and Remedying s.")

Starting a Dynamo.—In the case of a dynamo it is usually brought up to speed either by starting up a steam engine or by connecting the dynamo to a source of power already in motion. The former should of course only be attempted by a person competent to manage steam engines and familiar with the particular type in question. This requires special knowledge acquired by experience, as there are many points to appreciate and attend to, the neglect of any of which might cause serious trouble. For example, the presence of water in the cylinder might knock out the cylinder head; the failure to properly set the feed of the oil cups might cause the piston rod, shaft or other part to cut, or other great or small damage might be done by ignorance or carelessness. The mere mechanical connecting of a dynamo to a source of power is usually not very difficult; nevertheless, it should be done carefully and intelligently, even if it only requires throwing in a friction clutch or shifting a belt from a loose pulley. To put a belt on a pulley in motion is difficult and dangerous, particularly if the belt is large or the speed is high, and should not be tried except by a person who knows just how to do it. Even if a stick is used for this purpose it is apt to be caught and thrown around by the machinery unless it is used in exactly the right way.

It has been customary to bring dynamos to full speed before the brushes are lowered into contact with the commutator, but there is no particular reason for this practice, provided the dynamo is not allowed to turn backwards, which sometimes occurs from carelessness in starting, and might injure copper brushes by causing them to catch in the commutator. If the brushes are put in contact before starting they can be more easily and perfectly adjusted, and the E. M. F. comes up slowly so that any fault or difficulty will develop gradually and can be corrected, or the machine stopped, before any injury is done to it or to the system. In fact, if the machine is working alone on a system and is absolutely free from any danger of short-cir-

cuiting any other machine or storage battery on the same circuit, it may be started up connected to the circuit, in which case the E. M. F. and current feel their way, so to speak, through the whole system, and any trouble manifests itself so slowly that it can be taken care of before serious injury results.

If, however, a dynamo is to be connected to another or to a circuit having other dynamos or a storage battery working upon it, the greatest care should be taken. In fact, this coupling together of dynamos can be done perfectly if exactly the correct method is followed, but is likely to cause serious trouble if any mistake is made.

Coupling Dynamos.—Two or more machines are often connected to a common circuit. This is especially the case in electric lighting where the number of lamps required to be fed varies so much that one dynamo may be sufficient for certain hours, but two, three or more machines may be required at other times.

Dynamos may be connected together either in parallel (multiple arc) or in series.

Dynamos in Parallel.—In this case the + terminals are connected together or to the same line and the — terminals are connected together or to the other line. The currents (*i. e.*, amperes) of the machines are thereby added but the E. M. F. (volts) are not increased. The chief condition for the running of dynamos in parallel is that their voltages should be equal but their current capacities may be different. For example: A dynamo producing 10 amperes may be connected to another generating 100 amperes, provided the voltages agree. Parallel working is therefore suited to constant potential circuits. A dynamo to be connected in parallel with others or with a storage battery must first be brought up to its proper E. M. F. speed and other working conditions, otherwise will short-circuit the system, and probably burn out armature. Its field magnetism must also be at full

strength owing to the fact that it generates no E. M. F. with no field magnetism. Hence it is well to find whether the pole-pieces are strongly magnetized by testing them with a piece of iron, and make sure of the proper working of the machine in all other respects before connecting the armature to the circuit. It is quite common for the field circuit to be open at some point and thus cause very serious results. In fact, a dynamo should not be connected to a circuit in parallel with others until its voltage has been

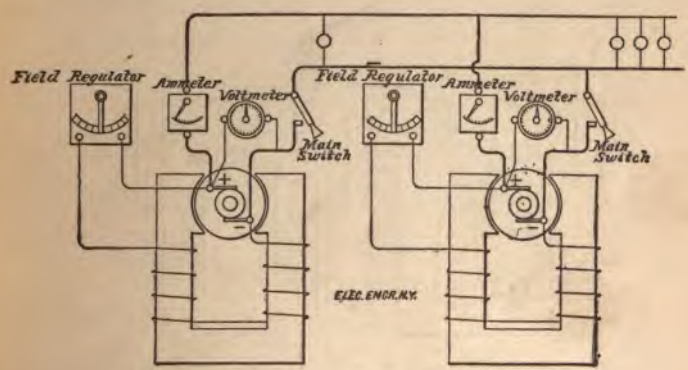


FIG. 10.—SHUNT DYNAMOS IN PARALLEL.

tested and found to be equal to or slightly (not over 1 or 2 per cent.) greater than that of the circuit. This test may be made by first measuring the E. M. F. of the circuit and then of the machine by one voltmeter; or voltmeters connected to each may be compared. Another method is to connect the dynamo to the circuit through a high resistance and a galvanometer, and when the latter indicates no current it shows that the voltage of the dynamo is equal to that of the circuit. A rougher and simpler way to do this is to raise the voltage of the dynamo until its "pilot

lamp," or other lamp fed by it, is fully as bright as the lamps on the circuit, and then connect the dynamo to the circuit. Of course the lamps compared should be intended for the same voltage and in normal condition. Be sure to connect the + terminal of the dynamo to the + wire and the — terminal to the — wire, otherwise there will be a very bad short-circuit.

When the dynamo is first connected in this way it should only supply a small amount of current to the circuit (as indicated by its ammeter) and its voltage should then be

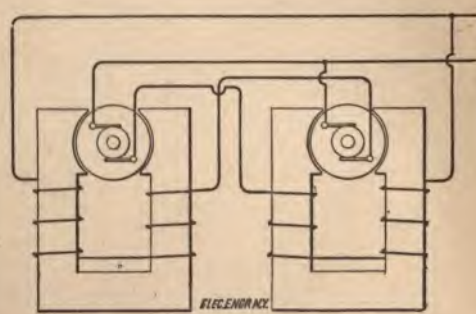


FIG. 11.—SERIES DYNAMOS IN PARALLEL.—MUTUAL ACTION.

gradually raised until it generates its proper share of the total current.

If the voltage of the dynamo is less than that of the circuit, the current will flow back into the dynamo and cause it to be run as a motor. If it is shunt wound the direction of rotation is the same, however, and no great harm results with a slight difference in voltage. Shunt machines are therefore particularly suited to being run in parallel, Fig. 10.

Series Wound Dynamos in Parallel.—If a machine is series wound, this back current would cause

a reversal of field magnetism and motion which is very objectionable. In fact, series dynamos in parallel are in very unstable equilibrium, because if either tends to generate too little current that very fact weakens its own field which is in series, and thus still further reduces its current and probably reverses it. One way to run series dynamos in parallel is to cause each to excite the other's field magnet, as shown in Fig. 11, whereby if one generates too much current it strengthens the field of the other and counteracts itself, so to speak.

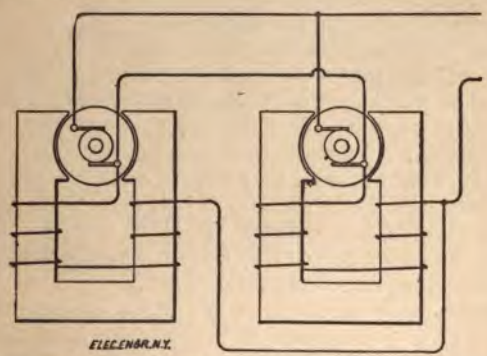


FIG. 12.—SERIES DYNAMOS IN PARALLEL.—EQUALIZING WIRE.

The other way, Fig. 12, to run series dynamos in parallel, is to connect together the two + brushes by what is called an "equalizer," as well as the two — brushes. By this means the electrical pressure at the terminals of the two armatures is made the same, and the currents in the two fields are also made equal. Series machines are not often run in parallel, but the principles just explained help the understanding of the next case, which is important.

Compound Dynamos in Parallel.—Since the field magnets of these machines are wound with series

coils as well as shunt, the coupling of them is a combination of the cases of the shunt and the series wound machines just described.

Fig. 13 represents two compound machines in parallel.

Assume that one machine is already running, that switches F^1 in the shunt circuit and s^1 in the main circuit are closed, and that armature No. 1 is generating its full current and feeding the lamps on the main circuit, the shunt and series field coils of the machine carrying their proper current. Now to throw on the other dynamo, its armature No. 2 is brought up to normal speed, switch F^2 is closed, which excites its shunt coil. Switch E, on the "equalizer" is then closed, which excites its series coil with part of the main current from No. 1. The second machine then gives its full voltage, and its main switch s^2 to make it produce its share of the current for the main is then closed and the voltage of the machine is regulated circuit. It would be well to actually compare the voltage before closing the main switch, as just described for shunt machines, making the voltage equal at first, so that the machine generates little or no current, and then raise it till the machine does its share of the work.

In disconnecting a machine the same steps are taken, only exactly in the reverse order. More than two compound machines may be run in parallel in this way by connecting them in a precisely similar manner.

Compound dynamos of different size or current capacity may also be coupled in this way, provided of course their voltages are equal, and provided also that the resistances of the series field coils are inversely proportional to the current capacities of the several machines, that is, if a dynamo produces twice as much current its series coil should have half the resistance.

The switch E is often left closed all the time, in fact, a permanent "equalizing," connection may be made between corresponding brushes of two or more machines. This ...e effect of "compounding" the dynamos collectively

instead of individually. For example, when only one dynamo is working, its current divides among the series coils of all and these coils will not be highly excited, when however all the dynamos are working the whole current of each will pass through its series coil. Thus the greatest field strength and therefore voltage is produced when

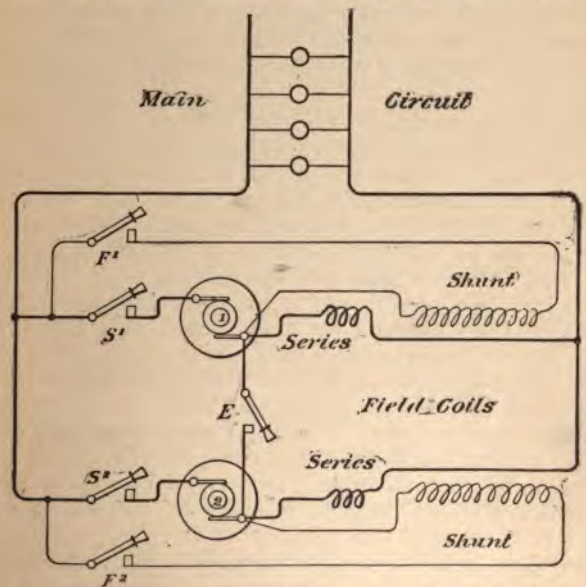


FIG. 13.—COMPOUND DYNAMOS IN PARALLEL.

most needed—at full load. The equalizing conductor should be able to carry at least half the full current of one dynamo. This method of running compound dynamos in parallel is important because it makes the effect of the series coil proportional to the total load, not to the load on each machine. This is particularly desirable in central

stations or where the dynamos are "overcompounded." Compound dynamos run in parallel in this way, as well as shunt machines, tend to steady each other, for if one happens to run too fast, it has to do more work which opposes the increase of speed, and it also takes part of the load off the other machines which will therefore tend to run faster, thus producing equality. This mutual regulation will take care of any slight difference between machines such as the slip of belt, but the difference must not be great.

Alternators in Parallel.—Since the alternating current consists of waves, it is necessary, in order to properly connect alternators together, that they should agree in two respects—first, in *frequency* or the number of waves produced per second, and second in *phase*, that is, they should be at corresponding points of the current waves at the same instant. The case is precisely similar to that of two persons walking together, they should not only have the same *rate* but they should also be in *step*. If an alternator is thrown into circuit with others when not in phase it will cause several severe fluctuations in the lamps, and then the machines will bring each other into unison since they exert a mutual control on each other, similar to that just described in the case of compound machines, only much stronger. In fact, an alternator resists being thrown out of step with others by an amount equal to the full torque or pull required to drive it.

Therefore to throw an alternator into circuit with others, bring its speed up to the proper point, regulate the field exciting current to make the voltage of the machine equal to that of the circuit.

The phase may then be determined by connecting one lamp to the secondary circuits of two transformers at the same time, one in circuit with the machine to be switched in and the other on the main circuit. The secondaries of, say, 50 volts each should be connected in series with each other and to a 100-volt lamp. When the machines are

opposed the lamp is dim, and vice versa. If the lamp flickers badly the phase is not right, but if the lamp is steady the machine is in phase and it may be connected by closing its main switch without disturbing the circuit. If dynamos are rigidly connected to each other or to the engine so that they necessarily run exactly together, there is no need of bringing them into step each time, but they should be adjusted to the same phase in the first place.

Dynamos in Series.—This arrangement is much less common than parallel working and does not usually

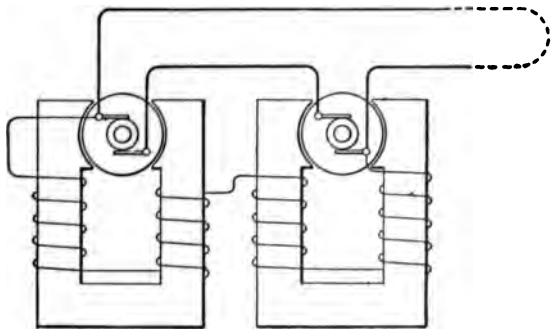


FIG. 14.—SHUNT DYNAMOS IN SERIES.

operate so well. The conditions are exactly opposite in the two cases.

To connect machines in series the + terminal of one must of course be connected to the — terminal of the next and so on. If dynamos are in series each of them must have a current capacity equal to the maximum current on the circuit, but they may differ to any extent in E. M. F. The voltages of machines in series are added together, and therefore danger to persons, insulation, etc., is increased in proportion.

Shunt or Compound Dynamos in Series may be run well, provided the shunt field coils are connected together to form one shunt across both machines as indicated in Fig. 14.

Series Wound Dynamos in Series may be connected in the simple way represented in Fig. 15, but usually machines are connected in series for arc lighting when, for example, two forty-light dynamos are run on

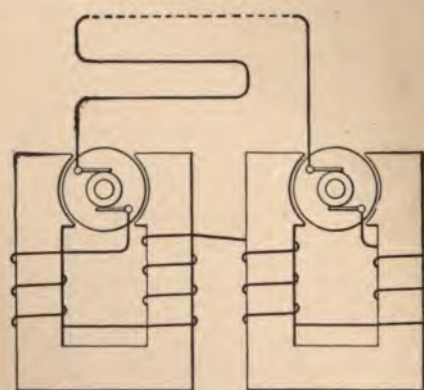


FIG. 15.—SERIES WOUND DYNAMOS IN SERIES.

one circuit of eighty lamps, in which case the dynamos usually have some form of regulator. These regulators do not work well together because they are apt to "see-saw" with each other. This difficulty may be overcome either by connecting the regulators so that they will work together or by setting one regulator to give full E. M. F. and let other alone control the current. This latter plan can be followed when the variation in load does not the power of one machine.

Alternators in Series.—The same mutual regulating tendency which makes alternators run well in parallel causes them to get out of step and become opposed to each other in series. It is impracticable to run them in series unless they are rigidly connected to run exactly in phase so that they add their waves of current instead of counteracting each other. This is a case that rarely arises in practice.

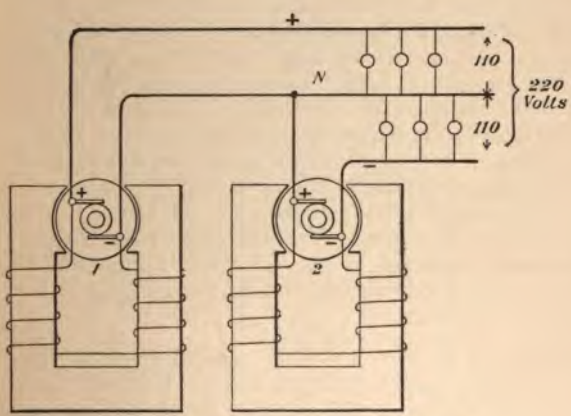


FIG. 16.—THREE-WIRE SYSTEM.

Dynamos on the Three-Wire System (Direct Current).—In the ordinary three-wire system for incandescent lighting as represented in Fig. 16, no particular precautions are required in starting or connecting dynamos. As a matter of fact the two dynamos are independent of each other and work on practically separate circuits. Dynamo 1 feeds the circuit formed by the mains marked + and N, and dynamo 2 feeds the circuit formed by mains N and—. The "neutral" wire N merely

acts as a common conductor for both circuits. The E. M. F. on each of these circuits should of course be kept constant at the prescribed voltage and therefore equal. The current on the two circuits or "sides" of the system as they are called, should be kept as nearly equal as possible by distributing the lamps equally between them. Any difference in current either way is carried by N. One dynamo may be run alone on one side of the system and the only effect of throwing on the other dynamo is to reduce the "drop" or fall of potential on the wire N. In fact if the load is equal on both sides there is practically no current or drop in N. If dynamos are put on the circuit in parallel also—for example, two in parallel on each side of the system, making four dynamos in all, then the machines on each side are managed simply as dynamos in parallel, as previously described. In starting up dynamos on the three-wire system, it is better to start one machine at a time and get that working properly as already described, and then put on a machine on the other side of the system to keep the two sides even. The addition of dynamos in parallel on each side should also be done singly just as on a simple two-wire circuit.

Starting Motors.—The general instructions relating to adjustment of brushes, screws, belt, oil cups, etc., given in the beginning of this chapter should be carefully followed preparatory to starting a motor.

The actual starting of a motor is usually a simple matter since it consists merely in operating a switch, but in each case there are one or more important points to consider.

Constant Potential Motor (Shunt Wound).—A motor, to run at constant speed on a constant potential circuit (a 110-volt incandescent lighting circuit, for example), is usually plain shunt wound. This is the commonest form of stationary motor. The field coils are wound with the right size of wire to take the proper magnetizing current as in the case of a shunt dynamo, and, since the potential

is constant, the field strength is constant. Shunt coils must not be used however if the potential is more than 5 per cent. higher, or 20 per cent. lower, than that for which they are intended, as stated elsewhere.

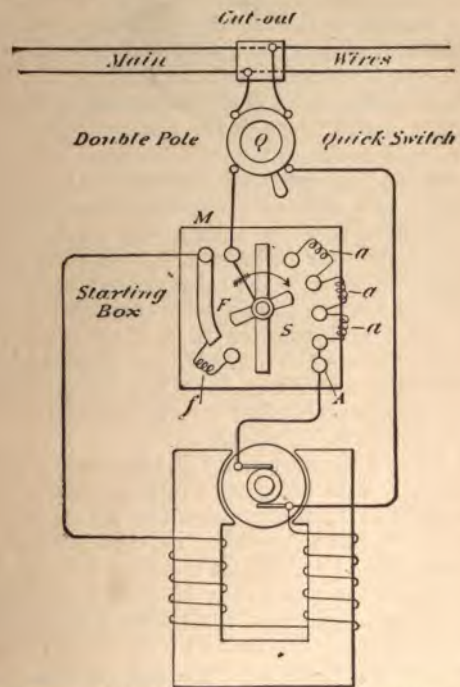


FIG. 17.—SHUNT MOTOR ON CONSTANT POTENTIAL CIRCUIT.

Throwing the field into circuit is therefore simple, but the current in the armature in starting is quite difficult to take care of, because the resistance of the armature is very low in order to get high efficiency and constancy of speed,

and the rush of current through it in starting might be ten or more times the normal number of amperes. To prevent this excessive current, motors are started on constant potential circuits through a rheostat or "starting box," containing resistance coils as represented in Fig. 17. The main wires are connected through a branch cut-out (with safety fuses) and preferably also a double-pole quick-break switch Q, to the motor and box as indicated. When the switch Q is closed and the arm S is turned to the right, the field circuit is closed through the contact strip F and the armature circuit is closed through the resistance coils *a*, *a*, *a* which prevent the rush of current referred to. The motor then starts and as its speed rises, it generates a counter E. M. F. so that the arm S can be turned further until all the resistance coils *a*, *a*, *a*, are cut out and the motor is directly connected to the circuit and running at full speed. The arm S should be turned slowly enough to allow the speed and counter E. M. F. to come up as the resistances *a*, *a*, *a* are cut out. The arm S should positively close the field circuit first so that the magnetism reaches its full strength (which takes several seconds) before the armature is connected.

The object of the resistance *f* is explained under "Stopping Motors." The coils *a*, *a*, *a*, are made of fine wire which can only carry the current for a few seconds in a "starting box"; but if the wire is large enough to carry the full current continuously it is called a "regulator" or rheostat because the arm S may be placed so that some of the resistances *a*, *a*, *a*, remain in circuit and they will have the effect of reducing the speed of the motor.

Constant Potential Motor (Series Wound).—The ordinary electric railway motor in the 500-volt trolley system is the chief example of this class. Motors for electric elevators and hoists are either of this kind or the previous one. A similar rush of current tends to occur when this type of motor is started as in the case just described, but it is somewhat less because the field coils

are in series and their resistance reduces the excess. The essential connections in this case as indicated in Fig. 18, are very simple, the armature, field coils F F, and rheostat, all being in series and carrying the same current. The series wound motor on a constant potential circuit does not have a constant field strength and does not tend to run at constant speed like a shunt motor. In fact it will "race" and tear itself apart if the load is taken off entirely, it is therefore only suited to railway, pump, fan or other work

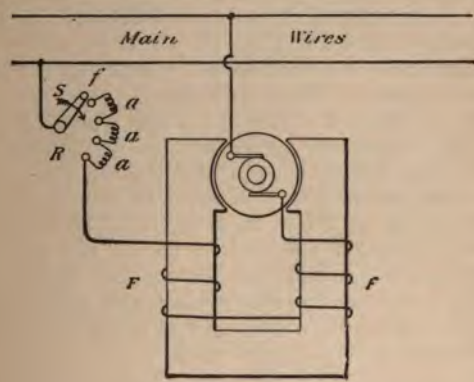


FIG. 18.

where variable speed is desired and where there is no danger of the load being removed or a belt slipping off.

Constant Potential Motor (Differentially Wound).—This is a shunt wound motor with the addition of a coil of large wire on the field and connected in series with the armature in such a way as to oppose the magnetizing effect of the shunt winding.

It was formerly much used to obtain very constant speed, but it has been found that a plain shunt motor is

sufficiently constant for almost all cases. The differential motor has the great disadvantage that, if overloaded, the current in the opposing (series) field coil becomes so great as to kill the field magnetism and the armature slows down or stops and is liable to burn out; whereas a plain shunt motor can increase its power greatly for a minute or so when overloaded and will probably throw off the belt or carry the load until it decreases to the normal amount.

Constant Current Motor.—The commonest example is a series wound motor on the arc circuit. The connections are shown in Fig. 19. The switch 1 is to entirely disconnect the circuit from the building in case of fire or other emergency. By simply turning the other switch 2 the motor is started or stopped, and since the current is constant the motor may be overloaded or held still without injury, whereas a constant potential motor would burn out.

The precaution necessary is never to touch the machine with current on, as the E. M. F. is probably high and very dangerous. Turn off the switch to fix the machine. A constant current motor should be provided with an effective centrifugal governor for controlling the speed, otherwise it will run away when the load is taken off, like a series motor on a constant potential circuit.

Alternating Current Motors.—These have not been very extensively used up to the present time, although a great variety of forms have been tried or suggested. Alternating motors are required to run on constant potential circuits since almost all alternating current systems are of this kind. But with alternating current there is no trouble from the rush of current which tends to occur in starting a motor with a constant potential direct current, because the self-induction of the field and armature coils prevents it. There are several types of alternating current motors. The simplest of these is a plain series or shunt machine the same as for direct current, except that

the field magnet is laminated as well as the armature. The trouble with this type, which has been used commercially in small sizes, is that bad sparking is apt to occur when the brush passes from one commutator bar to the next and short-circuits a coil which has alternating currents gener-

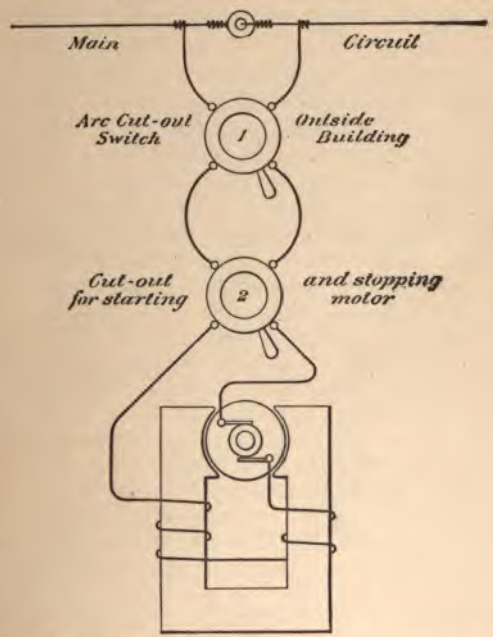


FIG. 19.—SERIES MOTOR ON CONSTANT CURRENT CIRCUIT.

ated in it by the reversals of the field magnetism. An ordinary alternating current dynamo can be used as a motor but its speed must be brought to agree with the current alternations before it will run, and then if it loses this exact speed it stops, and is therefore unpractical. In the

Tesla and other similar motors the effect is obtained by a rotary current, but this requires two or more currents of different phase and usually a special three-wire system would have to be put in before such motors could be operated.

Chapter V.

DIRECTIONS FOR RUNNING DYNAMOS AND MOTORS.

After one of these machines has been properly started as described in the previous chapter, it usually requires very little attention while running, in fact a dynamo or motor frequently runs well all day without any care whatever.

In the case of a machine which has not been run before or has been changed in any way, it is of course wise to watch it closely at first. It is also well to give the bearings of a new machine plenty of oil at first, but not enough to run on the armature, commutator or any part that would be injured by it, and to run the belt rather slack until the bearings and belt have gotten into easy working condition. If possible, a new machine should be run without load or with a light one for an hour or two, or several hours in the case of a large machine, and it is always very objectionable to start a new machine on full load.

This is true even if the machine has been fully tested by its manufacturer and is in perfect condition, because there may be some fault in setting it up or other circumstance which would cause trouble. All machinery requires some adjustment and care for a certain time to get it into smooth working order.

When this condition is reached the only attention required is to supply oil when needed, and see that the machine is not overloaded. The person in charge should always be ready and sure to detect any trouble such as sparking, the heating of any part of machine, noise, abnormally high or low speed, before any injury is caused and to overcome it by following the directions given in the chapter devoted to these troubles. Those directions should

be pretty thoroughly committed to mind in order to facilitate the prompt detection and remedy of any trouble when it suddenly occurs as is apt to be the case. If possible the machine should be shut down instantly when any trouble or indication of one appears, in order to avoid injury and give time for examination.

Keep all tools or pieces of iron or steel away from the machine while running, as they might be drawn in by the magnetism and perhaps get between the armature and pole-pieces and ruin the machine. For this reason use a zinc, brass or copper oil-can instead of iron or "tin" (which last is merely iron coated with tin).

FIG. 20.—TOOL INSULATED WITH RUBBER TAPE OR TUBING.

Never lift a commutator brush while machine is running as it might make a bad burnt spot, unless there is one or more other brushes on the same side to carry the current.

Touch the bearings and field coils occasionally to see that they are not hot. To determine whether the armature is running hot, place the hand in the current of air thrown out from the armature by centrifugal force.

Personal Safety.—Never close a circuit through the body. An accidental contact may be made through the feet, hands, knees, or other part of body in some peculiar and unexpected manner. For example, men have been killed because they were sitting on a conducting body.

Rubber gloves or rubber shoes, or both, should be used in handling circuits over 500 volts. The safest plan is not to touch any conductor while the current is on, and it should be remembered that the current may be present when not expected, due to an accidental contact with some other wire or a change of connections. Tools with insulated handles, Fig. 20, or a dry stick of wood should be used instead of the bare hand.

The rule to use *only one hand* when handling dangerous electrical conductors or apparatus, is a very good one, because it avoids the chance, which is very great, of making contacts with both hands and getting the full current right through the body. This rule is often made still more definite by saying, "Keep one hand in the pocket" in order to make sure not to use it. The above precautions are often totally disregarded, particularly by those who have become careless by familiarity with dangerous currents. The result of this has been that *almost all the persons accidentally killed by electricity have been experienced electric linemen or station men.*

Chapter VI.

DIRECTIONS FOR STOPPING DYNAMOS AND MOTORS.

This is accomplished by following substantially the same rules as those given for starting dynamos and motors in Chapter IV, only in the reverse order. But there are certain peculiar points to be observed in each case; so, in order to avoid any possible mistake, the matter of stopping is treated in this separate chapter. After any machine is stopped it should be thoroughly cleaned of dirt, copper dust and oil and put in perfect order for the next run. Switches, brushes, etc., should be fixed so that they will not accidentally close the circuit.

One Constant Potential Dynamo (Shunt, Series or Compound Wound) running *alone* on a circuit with no danger of receiving current from any other dynamo or battery, should be slowed down and stopped without touching the switches, brushes, etc., in which case the E. M. F. and current decrease gradually to zero as the speed goes down. The switches may then be opened and the brushes lifted without any spark. In the case of copper brushes this should be done just before the machine stops entirely, in order to avoid any injury to them if the machine turns back a little as sometimes occurs. Never switch out or disconnect a dynamo at full or even partial load except in extreme emergency, and the brushes should never be raised while the fields are strongly magnetized as the discharge of the magnetism may break lamps or pierce the insulation.

Dynamos in Parallel.—To stop a dynamo run- n parallel with one or more others or with a storage

battery on the same circuit (usually constant potential) regulate down its E. M. F. until it is only slightly greater than that of the circuit (about one per cent.) and its amperemeter shows that it is producing very little current; the switch connecting it to the circuit should then be quickly opened. Under no circumstances, however, should a dynamo in parallel with others or a battery be stopped, slowed down or have its field magnetism discharged or weakened (*i. e.*, more than enough to regulate its E. M. F. as stated) until its armature is completely disconnected from the circuit, as it might be burnt out or driven as a motor if its E. M. F. fell more than a few per cent.

Compound Wound Dynamos in Parallel may be stopped by exactly reversing the method for starting (Fig. 13) but if as there suggested the "equalizer" (E, Fig. 13) is left closed all the time the machines may then be stopped like simple shunt machines in parallel, as just described.

Dynamos on the Three-Wire (Direct) System are also stopped like dynamos on any constant potential circuit as explained in the chapter on starting.

Constant Current Dynamos and Motors in series may be cut out of, or into, the circuit without trouble and may be slowed down or stopped without disconnecting them from the circuit as the current is limited. If desired, the field coils may be short-circuited to stop the action of the machine while in circuit. The only precaution, and that is absolutely imperative, is to maintain the *continuity* of the circuit and never attempt to open it at any point as it would cause a dangerous arc. Hence a constant current machine must be *cut out* by first closing the main circuit around or past the machine and then entirely disconnecting it from the circuit, that is, both its wires or terminals.

One Alternator running *alone* on a circuit may be stopped or the field current shut off without trouble.

Alternators in Parallel may be disconnected from the circuit without the difficulty which is found in throwing them on, because it is not necessary to get them in phase.

A Constant Potential Motor is stopped by turning the starting box handle back to the position it had before starting (Fig. 17) or if there is a switch connecting motor to the circuit it may be opened. In the latter case a considerable spark will occur, but if it is a "quick-break" switch it may be better able to stand the spark than the starting box. The strictly best way is to turn the starting or regulating box arm back to the last contact point, which puts all the resistance in circuit, and then open the quick-break switch.

Either of these three ways is perfectly safe and the one may be adopted which trial shows to work best and burn contact points the least. A constant potential motor like the corresponding dynamos when in parallel, should never be stopped or much reduced in speed or have its field discharged or weakened until it is disconnected from the circuit, otherwise its counter E. M. F. is not enough to prevent an excessive current from rushing through its armature.

Thus it will be seen that the constant potential machine is exactly the opposite of the constant current. The former is safest when the circuit is open and it is very bad to short-circuit or stop it with the current on, whereas the latter is safest when the circuit is closed, and the machine may be stopped or short-circuited while in circuit.

stopped or short-circuited while in circuit. But the dynamo supplying the circuit *must* have an effective regulator to maintain the current of uniform volume, no matter how many lamps or motors are cut into or out of the circuit.

Chapter VII.

DIRECTIONS FOR TESTING DYNAMOS AND MOTORS.

The matter of testing dynamos and motors is of special importance since it is only by a thorough test that either the manufacturer or the user can determine whether a certain machine is up to the standard. Nevertheless it is difficult, if not impossible, to find in books or journals anything like a complete system of testing methods applicable to dynamos or motors. Each electrical manufacturer or engineer has collected by experience certain methods, but these usually apply to particular forms of machine or testing apparatus and moreover are often guarded as trade secrets.

The following methods cover the various facts about a dynamo or motor which one is likely to want to test. Under each heading exact methods are given which should, of course, always be preferred; but wherever possible we have also given simple, rough methods for emergencies or other cases in which a dynamo or motor may have to be tested without the accurate and expensive instruments required for the more refined methods.

This subject differs from our chapter on "Locating and Remedying Troubles in Dynamos or Motors," in the fact that the other relates to actual faults which are already apparent, whereas testing applies to any machine whether in perfect working condition or containing some latent fault which a test brings out and anticipates. The testing methods here given can also be used as supplementary to the methods for locating troubles in cases where a more complete investigation may be desirable. In testing any machine it is well to follow as nearly as possible the directions given by its maker and try it under the conditions

for which it is intended, in regard to voltage, current, speed, etc. Tests of dynamos and motors may cover any or all of the following points:

1. Adjustment and fit of parts.

2. Mechanical Strength of parts against breaking or displacement.

3. Friction of bearings and brushes.

4. Balance of armature and pulley.

5. Noise.

6. Electrical Resistance of conductors and insulation.

7. Voltage, E. M. F., "drop" or fall of potential, etc.

8. Current in field, armature free and loaded.

9. Speed of armature, free and loaded.

10. Torque or Pull, standing or running.

11. Power, electrical and mechanical.

12. Efficiency, electrical and commercial.

13. Heating of armature, field magnet, bearings, etc.

14. Sparking at commutator.

15. Magnetism, total flux, intensity, leakage and distribution.

16. Line or Circuit testing for resistance, insulation, faults, etc.

1. Adjustment and the other points which depend merely upon mechanical construction are hardly capable of being investigated by a regular quantitative test, but they and should be determined by thorough inspection. In very careful examination of all parts of a machine always precede any test of it. This should be done asons, first, to get the machine into proper con-

dition for a fair test, and second, to determine whether the materials and workmanship are of first-class quality and satisfactory in every respect. A loose screw or connection might interfere with a good test, and a poorly fitted bearing, brush holder, etc., might show that the machine was badly made.

If it is necessary to take the machine apart for cleaning or inspection the greatest care should be exercised in marking, numbering and placing the parts in order to be sure to get them together in exactly the same position as before. In taking apart or putting together a machine, only the minimum force should be used. Much force usually means that something wrong is being done or in a wrong way. A wooden mallet is preferable to an iron hammer, since it does not mar or strain the parts so much. Usually screws, nuts and other parts should be set up fairly tight but not tight enough to run any risk of breaking or straining anything. Shaking or feeling each screw or other part will almost always show that some one or more of them are too loose or too tight, or otherwise out of adjustment.

2. Mechanical Strength of a dynamo or motor is best specified by stating that it should be above question. The base, bearings, shaft, armature, field magnets and other main parts of the machine should not spring even one one-hundredth of an inch with any reasonable force that may be applied to them. There has long existed a craze for very light dynamos and motors, as a result of which, strength, rigidity, durability and satisfactory qualities in general have been sacrificed to reduce weight. There is certainly no sense in this. For stationary machines and even for ship dynamos or railway motors good solid frames, bearings, etc., are much better than light ones.

The magnetic attraction between the field and armature is often very great, and may amount to hundreds, or even thousands, of pounds. This tends to draw the pole-pieces against the armature, or spring the armature shaft if the armature is even slightly nearer one pole-piece than the

other. It is well to magnetize the field by putting the proper current through its coils and see if it produces any reduction of the clearance or other displacement that is appreciable to the eye or even to any ordinary measurement. The effect of the maximum pull of the belt or any other legitimate stress may be tested in the same way.

In addition to this all the parts of the machine should be scrutinized to see if they are of adequate size and proper proportion.

3. Friction.—The friction of the bearings and brushes can be tested roughly by merely revolving the armature by hand and noting if it requires more than the normal amount of force. Excessive friction is quite easily distinguished even by inexperienced persons. Another method is to cause the armature to revolve by hand or otherwise and see if it continues to revolve by itself freely for some time. A well-made machine in good condition will continue to run for one or more minutes after the turning force is removed.

A method for actually measuring the friction consists in attaching a lever (a bar of wood, for example) to the shaft or pulley at right angles to the former. The force required to overcome the friction and turn the armature without current is then determined by known weights or, more conveniently, by an ordinary spring balance. The friction of the bearings alone, that is, the pull required to turn the armature when the brushes are lifted off the commutator and there is no current or magnetism in the field, should not exceed 1 per cent. of the total torque or turning force of the machine at full load. When the brushes are in contact with the commutator with the usual pressure, the friction should then not exceed 2 per cent., that is, the brushes themselves should not consume more than 1 per cent. of the total turning force. When the field magnetism is at full strength, and the brushes are on the commutator, the maximum friction or pull required to turn the armature should, then, not exceed 4 per cent. of the total torque.

This torque or pull in pounds in the case of any machine may be calculated by the formula :

$$\text{Torque} = \frac{\text{H. P.} \times 33{,}000}{6.28 \times R \times S}$$

in which H. P. is the horse power of the machine at full load, R is the radius or length in feet of the lever used in the test, and S is the speed of the machine in revolutions per minute at full load.

Another method of measuring the friction of a machine is to run it by another machine used as a motor and determine the volts and amperes required, first, with brushes lifted off and no field magnetism ; second, with brushes on commutator but no magnetism ; and third, with full strength of field magnetism giving maximum friction. The torque or force exerted by the driving machine is afterwards measured by a Prony brake in the manner described hereafter for testing torque ; care being taken to make the Prony brake measurements at exactly the same volts and amperes as were required in the friction tests. In this way the torques which were exerted by the driving machine to overcome friction in each of the three first tests are determined, and these torques compared with the total torque of the machine being tested, as calculated by the formula just given, should give percentages not exceeding those stated above for the maximum values of friction.

Tests for friction alone should be made at a low speed because at high speeds the effect of Foucault currents and hysteresis enter and materially increase the apparent friction.

4. Balance.—The perfection of balance of the armature or pulley can be roughly tested by simply running the machine at its normal speed and noting if these parts are sufficiently well balanced not to cause any objectionable vibration. Of course, practically every machine produces perceptible vibration when running, but this should not be

more than a slight trembling. The balance of a machine can be definitely tested and the extent of the vibration measured by suspending the machine or mounting it on wheels and running it at full speed. In this case it is better to run the machine as a motor, even though it be actually a dynamo, in order to make it produce its own motion, so to speak, and avoid the necessity of running it by a belt which would cause vibration and interfere with the test. If, however, the use of a belt is unavoidable, it should be arranged to run vertically upward or downward so as not to produce any horizontal motion in addition to the vibration of the machine itself. Fig. 21 shows a machine hung up to be tested for balance and run either as a motor or by the vertical belt indicated as a dotted line. Any lack of balance will cause the machine to vibrate or swing horizontally, and this motion can be measured on a fixed scale.

5. Noise.—This cannot be well tested quantitatively, although it is very desirable that a machine should make as little noise as possible. Noise is produced by the various causes given in the chapters on Locating Faults. The machine should be run at full speed and any noise and its cause carefully noted.

6. Electrical Resistance.—There are two principal classes of resistance tests that have to be made in connection with dynamos and motors. First, the resistance of the wires or conductors themselves, which might be called the *metallic* resistance; and second, the resistance of the insulation of the wires, which is called the *insulation* resistance. The former should usually be as low as possible, the latter should always be as high as possible, because a low insulation resistance not only allows current to leak, but also causes "burn-outs" and other accidents. Metallic resistance, such, for example, as the resistance of the armature or field coils, is commonly tested either by the Wheatstone bridge or the "drop" (fall of potential) od.

The Wheatstone bridge, Fig. 23, is simply a number of branch circuits connected as indicated in Fig. 22. A, B and C are resistances the values of which are known. D is the

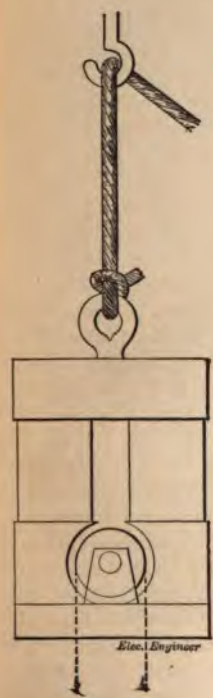


FIG. 21.

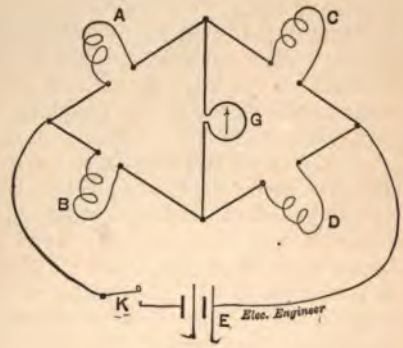


FIG. 22.

resistance which is being measured. G is a galvanometer and E is a battery of one or two cells controlled by a key K, all being connected exactly as shown. The resistance C is varied until the galvanometer shows no deflection when

the key K is closed. The value of the resistance D is then found by multiplying together resistances C and B and dividing by A; that is, $D = \frac{C \times B}{A}$. A very convenient form of this apparatus is what is known as the portable bridge. This consists of a box containing the three sets of known resistances A, B and C controlled by plugs, also the galvanometer G and key K, all connected in the proper way. In some cases the perfection of convenience is reached by including the battery E in the box also, but ordinarily this is not done and it is necessary to connect one or two cells of battery to a pair of binding posts placed on the box for that purpose. Resistances from $\frac{1}{10}$ ohm to 100,000 ohms can be conveniently and accurately measured by the Wheatstone bridge. Below $\frac{1}{10}$ ohm the resistances of the contacts in the binding posts and plugs are apt to cause errors. In fact, in measuring any resistance care should be taken to make the connections clean and tight. The ordinary bridge will not measure above 100,000 ohms because if the resistance in the arm B is 100 ohms, 1 ohm in A, and 1,000 ohms in C, then D is 100,000. Sometimes the arms A and B are provided with 1,000-ohm coils in addition to the usual 1, 10 and 100 ohm coils, or sometimes the arm C contains more than 1,000 ohms in all; in either case the range will be correspondingly increased. The bridge may be used for testing the resistance of almost any field coils that are found in practice. Shunt fields for 110-volt machines usually vary from about 100 or 200 ohms in a 1 h. p. machine to about 10 or 20 ohms in a 100 h. p. machine. If the voltage is higher or lower than 110 these resistances vary in direct proportion. Series fields for arc circuit dynamos or motors vary from about 1 to 20 ohms.

The bridge may also be used for testing the armature resistance of most machines. But 110-volt shunt machines above 10 h. p. usually have resistances below $\frac{1}{10}$ ohm, which below the range of the bridge, as already stated. Higher ge dynamos and motors have proportionally higher

resistance armatures. Arc machines have armatures of about 1 to 20 ohms resistance and are therefore easily tested by the bridge.

The "drop" or fall of potential method is well adapted to testing the armature resistance of large incandescent dynamos or the resistance of contact between commutator and brushes or other resistances which are usually only a few

FIG. 23.—PORTABLE WHEATSTONE BRIDGE.

hundredths or even thousandths of an ohm. This consists in passing a current through the armature and a known resistance of, say, $\frac{1}{100}$ ohm connected in series with each other, as represented in Fig. 24. The "drop" or fall of potential in the armature and in the known resistance are then compared by connecting a galvanometer first to the terminals marked 1 and 2 and then to 3 and 4. The deflections of the needle in the two cases are proportional to

the resistances. The current needed depends upon the sensitiveness of the galvanometer, but should not require more than a few cells of battery. If a galvanometer is not at hand, the drop method can be used with a strong current and a voltmeter, the connections being the same as in Fig. 23. The current required in this case depends upon the resistance to be measured, but it must of course be sufficient to produce a readable deflection on the voltmeter. Usually 10 to 100 amperes and a voltmeter reading to a single volt or fractions of one volt are needed for low resistances.

It is wise to start with a small current and increase it until a reasonably readable deflection is obtained on the

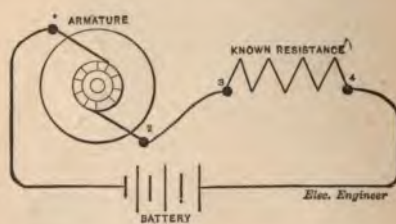


FIG. 24.

voltmeter. The current may be obtained by using a cell of storage battery, or a few cells of some strong primary battery such as a plunge battery, Bunsen or bichoromate battery. The current may also be taken from another dynamo or from a circuit, but a bank of lamps or a liquid resistance should then be used to control the current, as the armature alone, of course, has very little resistance. A convenient form of liquid resistance for this purpose is described ereafter in the directions for testing current (No. 8.)

The insulation resistance of a dynamo or motor, that is, ›sistance between its wires and its frame should be at ›ne megohm per hundred volts E. M. F., and it is, of

course, better if it is much higher. It is therefore beyond the range of ordinary Wheatstone bridge tests, but there are two good methods which are applicable—the "direct deflection" method and the voltmeter method. The direct deflection method is carried out by connecting a sensitive galvanometer such as a Thomson high resistance reflecting galvanometer (tripod or square pattern) in series with a known high resistance, usually a 100,000 ohm rheostat, a battery and a key as shown in Fig. 25. The galvanometer should be shunted with the $\frac{1}{999}$ coil of the shunt so that only $\frac{1}{1000}$ of the current passes through the galvanometer, the machine being entirely disconnected. The key is closed and the steady deflection noted. It is well to use only one cell of battery at first and then increase

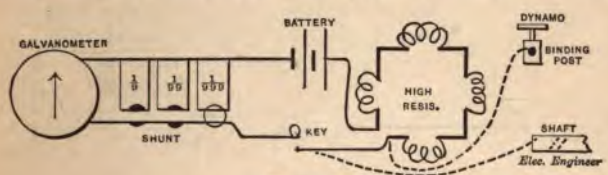


FIG. 25.

the number if necessary until a considerable deflection is obtained. One of the wires is then connected to the binding post or commutator of the dynamo or motor and the other to the frame or shaft of the machine as indicated by dotted lines. The key is closed and the deflection noted. Probably there will be little or no deflection on account of the high insulation resistance, and the shunt is changed to $\frac{1}{999}$, $\frac{1}{9}$ or left out entirely if little deflection is obtained. In changing the shunt, the key should always be open, otherwise the full current is thrown on the galvanometer. The insulation is then calculated by the formula: Insulation resistance $= \frac{D \times R \times S}{d}$, in which D is the first deflection without the machine connected and d the deflection with

the insulation in the circuit, R the known high resistance and S the ratio of the shunt. That is, if the shunt is $\frac{1}{999}$ in the first test and $\frac{1}{9}$ in the second, then S is 100, and if the shunt is out entirely in the second test S is 1,000. It is safer to leave the high resistance in circuit in the second test to protect the galvanometer in case the insulation resistance is low. Therefore this resistance must be subtracted from the result to obtain the insulation itself. By the above method it is possible to measure 100 megohms, or even more. The wires and connections should be carefully arranged to avoid any possibility of contact or leakage which would spoil the test.

The voltmeter test for insulation resistance requires a sensitive high resistance voltmeter such as the Weston.

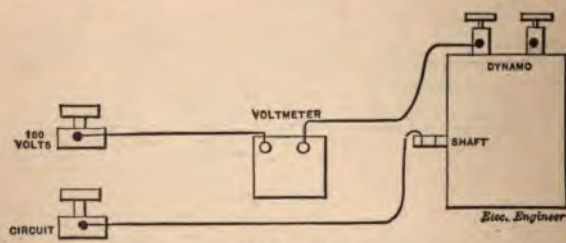


FIG. 26.

Take, for example, the 150-volt instrument which usually has about 15,000 ohms resistance; apply it to some circuit or battery and measure the voltage. This should be as high as possible; say, 100 volts. The insulation resistance of the machine is then connected into the circuit as indicated in Fig. 26. The deflection of the voltmeter is then reduced proportion to the value of the insulation resistance. insulation is then found by the equation : Insulation ice $= \frac{D \times R}{d} - R$, in which D is the first, and nd deflection and R the resistance of the volt-

meter. If the circuit is 100 volts then D is 100; and if d, the deflection through the insulation resistance of the machine, is 1 division, then the insulation is: (100 × 15,000) — 15,000 = 1,485,000 ohms. This method does not test very high resistances, but if little or no deflection is obtained through the insulation resistance it shows that it is at least several megohms, which is high enough for practical purposes.

The ordinary magneto bell may be used to test insulation by simply connecting one terminal to the binding post of the machine and the other to the frame or shaft.

A magneto bell is rated to ring through a certain resistance, usually from 10,000 to 30,000 ohms, and if it does not ring it shows that the insulation is more than that amount. This limit is altogether too low for proper insulation in any case, and therefore this test is rough and really only shows whether the insulation is very poor or the machine actually grounded.

7. Voltage.—There is no convenient way of testing voltage except by means of a voltmeter. Unfortunately a really satisfactory voltmeter is rather an expensive instrument. A good voltmeter should be very accurately calibrated because an error of one per cent. in the voltage of an incandescent circuit is objectionable, whereas the same error would be insignificant in almost any other practical measurement. A voltmeter should have as high a resistance as possible—at least several hundreds or thousands of ohms—in order not to take too much current which might lower its reading on a high resistance circuit. It should not be affected by the magnetism of a dynamo or motor at any distance over four or five feet. The voltage of any machine or circuit is tested by merely connecting the two binding posts or terminals of the voltmeter to the two terminals or conductors of the machine or circuit. In the case of a dynamo or motor the voltmeter is usually applied to the two main binding posts or brushes of the machine to get the external voltage of the machine. This external voltage

is what a dynamo supplies to the circuit and it is what a motor receives from the circuit. This is called the pole difference of potential or terminal voltage and is the actual figure upon which calculations of the efficiency, capacity, etc., of any machine are based.

A dynamo for constant potential circuits should, of course, give as nearly as possible a constant voltage. A plain shunt machine usually falls from 3 to 10 per cent. in voltage when its current is varied from nothing to full load. This is due to the loss of voltage in the resistance of the armature, which in turn weakens the field current and magnetism; armature reaction and reduction in speed usually occur also and still further lower the external voltage, but of course this variation is very undesirable. A compound-wound dynamo should not fall appreciably from no load to full load; in fact, if it is "over-compounded," it should rise two or three per cent. in voltage to make up for loss on the wiring. The voltage of a constant current dynamo or motor is not important. The current should be carefully measured by an amperemeter, but little or no attention is paid to the voltage in practical working; in fact, it changes constantly with variations in the load. It is of course necessary, however, to measure it for a test of efficiency or other exact tests.

A very simple and fairly accurate method of measuring voltage is by means of ordinary incandescent lamps. A little practice enables one to tell whether a lamp has its proper voltage and brightness. In this way it is easy to tell if the voltage is even one or two per cent. above or below the normal point. Voltages less than the ordinary can be tested by using low voltage lamps or by estimating the brightness of high voltage lamps. For example, a lamp begins to show a very dull red at one-third and a bright red at one-half its full voltage. Voltages higher than that of one lamp can be tested in this way by using lamps in series. In fact, even 1,000 or more volts can be measured by using 10 or more lamps in series.

8. Current.—This is, of course, measured by means of an amperemeter, and this instrument is usually cheaper than a voltmeter because it only contains a comparatively small amount of wire, and does not ordinarily require to be accurate within one or two per cent. In testing the current of a dynamo or motor all that is necessary is to connect an amperemeter of the proper range in series with the machine to be tested so that the whole current to be measured passes through the instrument. To test the current in the armature or field alone, the amperemeter is connected in series with the particular part. In the case of a shunt-wound dynamo it is well to entirely open the external circuit in testing the current used in the field coils in order to avoid mistake, for the same reason the brushes of a shunt motor should be raised while testing the current taken by the field. In a constant current (series wound) dynamo or motor the same current flows through all parts of the machine and the rest of the circuit, consequently the measurement of current is very simple.

In testing the current produced by a dynamo it is often quite a problem to consume it. A bank of lamps, for example, to use the whole current generated by a dynamo of 110 volts and 200 amperes would be very expensive. A sufficient number of resistance boxes for the purpose would also be very costly. The simplest and cheapest means to consume a large current is to place two plates of metal or carbon in a common tub or trough filled with a very dilute solution of sulphate of soda or sulphuric acid. The main conductors are connected to the two plates, respectively, and the current passed through the solution. The resistance and current are regulated by varying the distance between the plates and the depth they are immersed in the liquid. The energy may be sufficient to boil the liquid but this does no harm. As high as three amperes per sq. inch of exposed surface may be allowed. Strengthen solution or move plates together for low voltages.

9. Speed.—This is usually tested by the well-known speed meter or speed counter which consists merely of a little spindle which turns a wheel one tooth each time it

revolves. The point of the spindle is held against the centre of the shaft of the dynamo or motor for a certain time, say, one minute or one half minute, and the number of revolutions is read off from the position of the wheel.

Another instrument for measuring number of revolutions per minute is the tachometer. The stationary form of this instrument is shown in Fig. 27. This requires to be belted by a string, tape or light leather belt to the machine the speed of which is to be tested. If the sizes of the pulleys are not the same, their speeds are inversely proportional to their diameters. The portable form of this instrument is applied directly to the end of the shaft of the machine

FIG. 27.

like the speed meter. These instruments possess the great advantage over the speed meter that they instantly point on the dial to the proper speed and they do not require to be timed for a certain period.

A simple way to test revolutions per minute is to make one large black or white mark on the belt of a machine and note how many times the mark passes per minute; the length of the belt divided by the circumference of the pulley gives the number of revolutions of the pulley for each time the mark passes. If the machine has no belt, it can be supplied with one temporarily for the purpose of the test, a piece of tape with a knot or an ink mark being

sufficient. Care should be taken in all these tests of speed with belts, not to allow any slip; for example, in the case of the tape belt just referred to, it should pass around the pulley of the machine and some light wheel of wood or metal which turns so easily as not to cause any slip of the belt on the pulley of the machine.

10. Torque or Pull is tested in the case of a motor by the use of a Prony brake. This consists of a lever L L

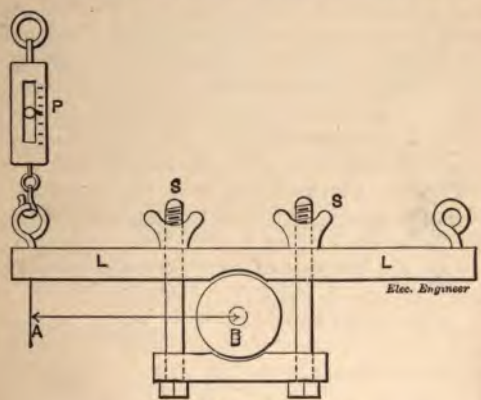


FIG. 28.

of wood clamped on to the pulley or shaft of the machine to be tested, as indicated in Fig. 28. The pressure of the screws s s is then adjusted by the wing nuts until the friction of the clamp on the pulley is sufficient to cause the motor to take a given current and run at a given speed. Usually the maximum torque or pull is the most important to test and this is obtained in the case of a constant potential motor by tightening the screws s s until the motor draws its full current as indicated by an amperemeter. What the full current should be, is usually marked on the

name plate; if not, it may be assumed to be about 8 amperes per h. p. for 110-volt motors, 4 amperes per h. p. for 220-volt and $1\frac{3}{4}$ ampere per h. p. for 500-volt motors. The torque or pull is then measured by known weights, or more conveniently by a spring balance P. If desired, the test may also be made at three-quarters, one-half or any other fraction of the full current.

The torque or pull of a constant current motor is found by adjusting the screws S S until the armature runs at its normal speed.

The torque or pull of a dynamo, that is, the force required to drive it, is tested by a transmission dynamometer. There are several forms of this apparatus but none of them are very satisfactory. In the cradle dynamometer the dynamo is placed on a platform which is hung on a pivot or fulcrum. The axis of the shaft of the dynamo is adjusted so that it exactly coincides with the axis of the pivot or fulcrum. When the dynamo is run by a vertical belt, the pull or torque tends to cause the dynamo to turn about its axis of suspension, and the force of this torque is measured by the amount of weights required to keep the dynamo and platform horizontal. In a modified form of the cradle dynamometer the dynamo is placed in a water-tight box which floats in another box filled with water, instead of being hung on a pivot. It is usually much easier to test the torque of a dynamo by running it as a motor and testing it by the Prony brake method described above. The torque of a dynamo is practically equal to that of a motor under identical conditions.

11. Power.—The electrical power of a dynamo or motor is found by testing the voltage and current at the terminals of the machine, as described in sections 7 and 8 of this chapter, and multiplying the two together, which gives the electrical power of the machine in watts. These watts divided by 746 are then converted into horse power, thus:

$$\text{Horse power} = \frac{\text{volts} \times \text{amperes}}{746}.$$

The mechanical power of a dynamo or motor, that is, the power required for or developed by it is found by multiplying its torque or pull, determined as described in the previous paragraph, by its speed, determined as described in section 9 of the present chapter, and by the circumference of the circle on which the torque is measured, and dividing by 33,000, that is—

$$\text{Horse power} = \frac{P \times S \times 6.28 \times R}{33{,}000}$$

in which P is the torque in pounds, S the speed in revolutions per minute and R the radius at which P is measured.

12. Efficiency.—This is determined in the case of a dynamo by comparing the mechanical power required to drive it by the electrical power generated by it, that is—

$$\text{Efficiency of dynamo} = \frac{\text{Electrical power}}{\text{Mechanical power}}.$$

The efficiency of a motor is the mechanical power developed by it divided by the electrical power supplied to it, that is—

$$\text{Efficiency of motor} = \frac{\text{Mechanical power}}{\text{Electrical power}}$$

These are the *actual* or *commercial* efficiencies of these machines and should be about 90 per cent. in machines of 10 h. p. and over.

The so-called "electrical efficiency" is misleading and of little practical importance and should not be considered in commercial work. The mechanical and electrical power in the above equations are determined as described in the last section.

13. Heating.—This is measured by applying a thermometer to the various parts of the machine, after it has run at full load for one or two hours, in fact a large machine does not reach its maximum temperature until it has run for three or four hours.

The bulb of the thermometer is applied directly to the surface of the field coil or other part. To test the armature

it must, of course, be stopped. The thermometer bulb should be covered over with a bunch of waste or cloth to keep in the heat. The temperature of the armature, field coils, bearings, etc., should not rise more than 40° C. or 72° F. above that of the surrounding air. A very simple test of heating is to apply the hand to the armature, etc., and if it can be kept on without great discomfort, the temperature is perfectly safe. (See "Heating" in chapters on Locating Faults.)

14. Sparking at the commutator cannot be actually measured, but it is a very important matter and in any test it should be carefully observed whether the sparking is excessive or not, and if so, what it is due to. (See "Sparking" in chapters on Locating Faults.)

15. Magnetism.—Magnetic measurements are difficult to make with the ordinary apparatus used in practical work. The proper method of testing magnetism is with the ballistic galvanometer. To test the magnetic leakage in a dynamo or motor, for example, a coil of wire connected to the galvanometer is put around the field magnet and the current in the field is stopped the deflection of the galvanometer needle being noted. A coil of the same number of turns is then put around the armature and the swing of the galvanometer is again noted. The first deflection is to the second as the number of lines of magnetic force in the field is to those in the armature, provided the angles of deflection are only a few degrees.

An ordinary detector galvanometer can be used for this work if it is not damped by wings to prevent its swinging freely. A low-voltage Weston voltmeter or the calibration coil of a high-reading one, can also be used very conveniently for magnetic measurements in place of the galvanometer as described by A. S. Ives in the *Electrical World*, Jan. 2, 1892.

16. Line or Circuit testing for resistance, insu- current, voltage, etc., is performed by exactly the

same methods as those just described for making the corresponding tests on dynamos and motors. For example, in testing the insulation resistance of a line or circuit, one wire is connected to the line and the other to the ground (a gas or water pipe is convenient for this purpose) instead of connecting one wire to the commutator and the other to the frame of the machine as described for testing the insulation resistance of a dynamo, otherwise the test is exactly the same.

THE

LOCALIZATION AND REMEDY

OF

TROUBLES IN DYNAMOS OR MOTORS.

INTRODUCTION.

THE promptness and ease with which any accident or difficulty with electrical machinery may be dealt with, whether by the inspector of construction or by the operator in charge of running, will always have much to do with the success of the plant and of those dependent upon it. It is therefore likely that any method to eliminate or reduce these troubles would be very welcome to those handling dynamos and motors. With the object of obtaining such a method, we have prepared a list of troubles, symptoms and remedies, based upon quite an extensive experience with the various types and sizes of dynamos and motors in common use.

It is evident that this subject is somewhat complicated and difficult to handle in a general way, since so much depends upon the particular conditions in any given case, every one of which must be included in the table in such a way as to distinguish it from all others. Nevertheless, it is quite remarkable how much can be covered by a systematic and reasonably simple statement of the matter, and we feel confident that nearly all of the cases of trouble most likely to occur are covered by the table, and that the

detection and remedy of the defect will result from a proper application of the rules given.

It frequently happens that a trifling oversight, such as allowing a wire to slip out of a binding-post, will cause as much annoyance and delay in the use of electrical machinery as the most serious accident. Other troubles, equally simple but not as easily detected, are of frequent occurrence. In such cases a very slight knowledge on the part of a man having the machine in charge, guided by a correct set of rules, will enable him to overcome the difficulty immediately and save much time, trouble and expense.

It must not be supposed that this method for treating dynamo and motor troubles is given because these machines are particularly liable to such difficulties. On the contrary, no machine in existence is mechanically simpler than the dynamo or motor. The only wearing parts about the machine, with the exception of the commutator and brushes, which are specially made to stand almost unlimited wear without interfering with the action of the machine, are the two bearings. In this respect, therefore, the dynamo or motor is as simple as an ordinary grindstone, and infinitely simpler than a steam engine, which often has a dozen or more oil cups and several dozen wearing parts. Even a sewing machine is far more complicated mechanically than any dynamo or motor. In fact, it would be useless to attempt to give a method for detecting and curing dynamo and motor troubles if it were not for the fact that these machines consist of very few parts, which makes it reasonably possible to locate the trouble.

The rules are made, as far as possible, self-explanatory, but a statement of the general plan followed and its most important features will facilitate the understanding and use of the table.

USE OF THE TABLE OF TROUBLES.

In the use of this table the principal object should also clearly separate the various causes and effects

from each other. A careful and thorough examination should first be made, and as far as possible one should be perfectly sure of the facts, rather than attempt to guess what they are and jump at conclusions. Of course general precautions and preventive measures should be taken *before* any troubles occur, if possible, rather than wait until a difficulty has arisen. For example, see that machine is not overloaded or running at too high voltage, and make sure that the oil cups are not empty. Neglect and carelessness with any machine are usually and deservedly followed by accidents of some sort.

The general plan of the table is to divide all dynamo and motor troubles which are liable to occur into eight classes, the headings of which are the eight most important and obvious bad effects produced in these machines, viz :

No. 1. Sparking at Commutator.
No. 2. Heating of Armature.
No. 3. Heating of Field Magnets.
No. 4. Heating of Bearings.
No. 5. Noise.
No. 6. Speed too high or low.
No. 7. Motor stops or fails to start.
No. 8. Dynamo fails to generate.

Any one of these general effects is very obvious, even to the casual observer, and still more so to any one making a careful examination, and every one of these effects is perfectly distinguishable from any of the others without the least difficulty. Hence, this classification is perfectly definite and makes it easy to tell, almost at the first glance, under which one of these heads any trouble belongs, thereby eliminating about seven-eighths of the possible cases. The next step is to find out which particular one of the six or eight cases in this class is responsible for the trouble. This,

of course, requires more careful examination, but, nevertheless, can be done with comparative ease in most cases. Of course one cause may produce two effects, and, vice-versa, one effect may be produced by two causes ; but the table is arranged to cover this fact as far as possible. In a very complicated or difficult case it is well to read through the entire table and note what causes can possibly apply, and they will generally not be more than two or three, then proceed to pick out the particular one by following the directions which show how each case may be distinguished from any other. The table is intended for the use of those who build, test, install, own or operate electrical machinery, and all statements apply equally well to both dynamos and motors, unless otherwise specially noted.

Chapter I.

SPARKING AT COMMUTATOR.

1. Cause.—*Armature carrying too much current*, due to (*a*) overload (for example, too many lamps fed by dynamo, or too much mechanical work done by constant-potential motor); or (*b*) excessive voltage on a constant-potential circuit or excessive amperes on a constant-current circuit. In the case of a motor on a constant-potential circuit, any friction, such as armature striking pole-pieces or shaft not turning freely, will, of course, have the same effect as overload in producing excessive current. The armature of a motor on a constant-current circuit does not tend to heat more when overloaded, because the current and the heat it produces in the armature (C^2R) are constant. In fact, armature can be stopped with full current without injury except loss of ventilation.

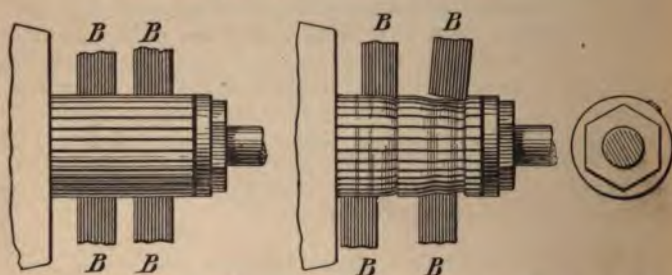
Symptom.—Whole armature becomes overheated and belt very tight on tension side and sometimes squeaks, due to slipping on pulley. Overload due to friction is detected by stopping machine and then turning it slowly by hand. See Heating of Bearings and Noise, No. 2.

REMEDY.—(*c*) Reduce the load; (*d*) decrease the size of driving pulley, or (*e*) increase the size of driven pulley; (*f*) decrease magnetic strength of the field in the case of a dynamo or increase it in the case of a motor. If excess of current cannot satisfactorily be overcome in any of the above ways it will probably be necessary to change the machine or its winding. Overload due to friction is eliminated as described under Heating of Bearings and Noise, No. 2.

2. Cause.—*Brushes not set at the neutral point.*

Symptom.—Sparking varied by shifting the brushes with rocker-arm.

REMEDY.—Carefully shift brushes back and forth until sparking is reduced to a minimum. This may be done by simply moving the rocker-arm, provided the brushes are set so as to touch diametrically opposite points on the commutator. If the brushes are not exactly opposite they should be made so, the proper points of contact being determined by counting the commutator bars or measuring with a piece of string or paper.



FIGS. 1, 2 AND 3.—1. COMMUTATOR IN GOOD CONDITION. 2. COMMUTATOR IN BAD CONDITION. 3. HIGH BAR ON COMMUTATOR.

3. Cause —*Commutator* (*a*) *rough*, (*b*) *eccentric, or* (*c*) *has one or more "high bars" projecting beyond the others, or* (*d*) *one or more flat bars, commonly called "flats,"* any one of which causes brush to vibrate or to be actually thrown out of contact with commutator. (Figs. 1, 2 and 3.)

Symptom.—(*e*) Note whether there is a glaze or polish on the commutator, which shows smooth working; (*f*) touch revolving commutator with tip of finger and the last roughness is perceptible. If the machine runs at high voltage (over 250) the commutator should be touched with

a small stick or quill to avoid danger of shock. In the case of an eccentric commutator, careful examination shows a rise and fall of the brush when commutator turns slowly.

REMEDY.—Smooth the commutator with file or fine sandpaper (in latter case be careful to remove sand and *never* use emery), or if commutator is very rough or eccentric, turn it off with a fine cut in a lathe.

In order to have the commutator wear smooth and work well it is desirable to have the armature shaft move freely back and forth about one-sixteenth or an eighth of an inch in the bearings, and the position of the bearings, pulley, collars and shoulders on the shaft and of the machine with respect to the belt should be such as to cause this to take place of itself. (See Heating of Bearings, No. 6.)

---

4. Cause.—*Brushes make poor contact with commutator.*

Symptom.—Close examination shows that brushes touch only at one corner, or only in front or behind, or there is dirt on surface of contact.

REMEDY.—File, bend, adjust or clean brushes until they rest evenly on commutator with considerable surface of contact and with sure but light pressure.

---

5. Cause.—*Short-circuited coil in armature.*

Symptom.—The particular commutator bar connected to short-circuited coil is burnt by the spark which occurs when brush passes over it.

The short-circuited coil is heated much more than the others, and is very apt to be burnt out entirely; therefore stop machine immediately. If necessary to run machine to locate the short circuit, one or two minutes is long enough, but it may be repeated until the heat of the short-circuited coil is found by touching the armature all over.

Considerable power is required to run armature free. An iron screw-driver or other tool held near the revolving armature vibrates perceptibly as short-circuited coil passes. Current pulsates and torque is unequal at different parts of a revolution, these being particularly noticeable when armature turns rather slowly. If a large portion of the armature is short circuited the heating is distributed and harder to locate. In this case a motor runs very slowly with very little power, but full field magnetism. (For dynamos, see Dynamo Fails to Generate, No. 3.)

REMEDY.—A short circuit is often caused by a piece of solder or other metal getting between the commutator bars or their connections with the armature, and sometimes the insulation between these bars is bridged over by a particle of metal. In any such case the trouble is easily found and corrected. If, however, the short circuit is in the coil itself, the only real cure is to rewind the coil.

In an emergency a short-circuited coil may be temporarily cut out by connecting together the two commutator bars to which its terminals are connected or the two adjacent coils, as described in the Remedy for Sparking, No. 6. But be sure to unwind or open the circuit of the short-circuited coil, as otherwise the trouble will continue.

---

6. Cause.—*Broken circuit in armature.*

Symptom.—Commutator flashes violently while running and commutator bar nearest the break is badly cut and burnt, but in this case no particular armature coil will be heated, as in the last case (No. 5), and the flashing will be very much worse, even when turning slowly. This trouble, which might also be confounded with a bad case of "high bar" or eccentricity in commutator (Sparking, No. 3), is distinguished from it by slowly turning the armature, when violent flashing will continue if circuit is open, but not with eccentric commutator or even with

"high bar," unless the latter is very bad, in which case it is easily felt or seen.

REMEDY.—The broken circuit is usually found where armature wires connect with commutator, and not in the coil itself, and the break may be repaired or the loose wire may be resoldered or screwed back in place. If the broken commutator connection cannot be fixed, then connect the disconnected bar to the next by solder, or "stagger" the brushes; that is, put one a little forward and the other back so as to bridge over the break (Fig. 4). If the break is in the coil itself, rewinding is generally the only cure. But this may be remedied temporarily by connecting together by wire or solder the two commutator bars

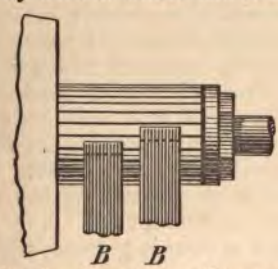


FIG. 4.—STAGGERED BRUSHES.

or coil terminals between which the break exists. It is only in an emergency that armature coils should be cut out or commutator bars connected together, or other makeshifts resorted to, but it sometimes avoids a very undesirable stoppage. A very rough, but nevertheless quick and simple, way to connect two commutator bars is to hammer or otherwise force the coppers together across the mica insulation at the end of the commutator. This can be afterwards easily picked out and smoothed over. In carrying out any of these methods care should be taken not to short circuit an armature coil, which would cause Sparking, No. 5.

7. Cause.— *Weak field magnetism.*

Symptom.—Pole-pieces not strongly magnetic when tested with a piece of iron. Point of least sparking is shifted considerably from normal position, due to relatively strong distorting effect of armature magnetism. Speed of a motor is usually high unless magnetism is very weak or nil, in which case a motor may run slow, stop, or even run backwards. A dynamo fails to generate the full E. M. F. or current. The particular cause of trouble may be found as follows: A broken circuit in the field is found by purposely opening the field circuit at some point, taking care to first disconnect armature (by putting wood under the brushes, for example) and to use only one hand to avoid shock, and if there is no spark there must be a broken circuit somewhere. A short circuit is found by measuring the resistance roughly to see if it is very much less than it should be, and usually a short circuit is confined to one magnet and will therefore weaken that particular one most, and a piece of iron held half-way between the pole-pieces will be attracted to one more than the other. "Grounding" is practically identical with short circuiting, since one ground would not produce this effect until another occurred, and then we should have a double ground, which is equivalent to a short circuit.

REMEDY.—A broken or a short circuit or a ground is easily repaired if it is external or accessible. If it is internal the only remedy is to rewind the faulty coil.

(See Speed Too High or Low; Motor Stops or Fails to Start; Dynamos Fail to Generate.)

Chapter II.

HEATING IN DYNAMO OR MOTOR.

GENERAL INSTRUCTIONS.

The degree of heat that is injurious, or even objectionable, in any part of a dynamo or motor is fortunately very easily and quite definitely determined in ordinary practice. All that is necessary is to place the hand on the various parts, and if it can remain without discomfort the heat is entirely harmless. But if the heat is unbearable for more than a few seconds, the safe limit of temperature has been passed, and it should be reduced in some of the ways that are given below. If the heat has become so great as to produce an odor or smoke, the safe limit has been far exceeded, and the current should be shut off and the machine stopped immediately, as this indicates a serious trouble, such as a short-circuited coil or a tight bearing. The machine should not again be started until the cause of the trouble has been found and positively overcome. Of course neither water nor ice should ever be used to cool electrical machinery, except possibly the bearings in large machines, where it can be applied to the bearings as a cooler without danger of wetting the other parts.

The above simple method will answer in ordinary cases, but, of course, the sensitiveness of the hand differs, and it makes a very great difference in the feeling whether bare metal or cotton-covered wire is touched. The back of the hand is more sensitive and less variable than the palm for this test. But for accurate results, a thermometer should be applied and covered with waste or cloth to keep in the heat. In proper working the temperature of no parts of the machine should rise more than 40° C. or 72° F.

above the temperature of the surrounding air. If the actual temperature of the machine reaches boiling point, 100° C. or 212° F., it is seriously high.

It is very important in all cases of heating to locate correctly the source of heat in the exact part in which it is produced. It is a common mistake to suppose that any part of a machine which is found to be hot is the seat of the trouble. In every case all parts of the machine should be felt to find which is the hottest, since heat generated in one part is rapidly diffused throughout the entire machine. It is generally much surer and easier in the end to make observations for heating by starting with the whole machine perfectly cool, which is done by letting it stand for one or more hours, or over night, before making the examination. When ready to try it, run it fast for three to five minutes, then stop and feel all parts immediately. The heat will then be found in the right place, as it will not have had time to diffuse from the heated to the cool parts of the machine. In fact, after the machine has run some time any heating effect will spread until all parts are nearly equal in temperature, and it will then be almost impossible to locate the trouble

Chapter III.

HEATING OF ARMATURE.

1. Cause.—*Excessive current in armature coils.* Symptom and Remedy the same as Sparking, No. 1.

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2. Cause.—*Short-circuited armature coils.* Symptom and Remedy the same as Sparking, No. 5.

---

3. Cause.—*Moisture in armature coils.*

Symptom.—Armature requires considerable power to run free. Armature steams when hot, or feels moist. This is really a special case of No. 2, as moisture has the effect of short circuiting the coils through the insulation. Measure insulation of armature.

REMEDY.—Dry the armature in a warm, but not hot, place. This may be done very neatly by passing a current through the armature, which should be regulated so as not to exceed the usual armature current.

---

4. Cause.—*Foucault currents in armature core.*

Symptom.—Iron of armature core hotter than coils after a short run, and considerable power required to run armature when field is magnetized and no load on armature. This may be distinguished from No. 2 by absence of sparking and absence of excessive heat in a particular coil or coils after a short run.

REMEDY.—Armature core should be laminated more perfectly, which is a matter of first construction.

Chapter IV.

HEATING OF FIELD MAGNET.

1. Cause.—*Excessive current in field circuit.*

Symptom.—Field coils too hot to keep the hand on.

REMEDY.—In the case of a shunt-wound machine decrease the voltage at terminals of field coils, or increase the resistance in field circuit by winding on more wire or putting resistance in series. In the case of a series-wound machine, shunt a portion of, or otherwise decrease, the current passing through field, or take a layer or more of wire off the field coils, or rewind with coarser wire. This trouble might be due to a short circuit in field coils in the case of a shunt-wound dynamo or motor, and would be indicated by one pole-piece with the short-circuited coil being weaker than the other; one of the coils would also probably be hotter than the other; but this can only be remedied by rewinding short-circuited coil. Measure resistance of field coils to see if they are nearly equal. If the difference is considerable (*i. e.* more than 5 or 10 per cent.) it is almost a sure sign that one or both coils are short circuited or double-grounded.

---

2. Cause.—*Foucault currents in pole-pieces.*

Symptom.—Pole-pieces hotter than coils after a short run. The pole-pieces being bare metal and coils being covered, when making comparison it is of course necessary to keep hand on coils some time before full effect is reached, and even then it is reduced.

REMEDY.—This trouble is either due to faulty design and construction, which can only be corrected by re-

building, or else it is caused by fluctuations in the current. The latter can be detected, if the variations are not too rapid, by putting an ammeter in circuit, or rapid variations may be felt by holding a piece of iron near the pole-pieces and noting whether it vibrates. A direct current does not usually vary enough to cause this trouble, but in the case of an alternating current it is necessary to use laminated fields to avoid great heating, and the ordinary arc currents fluctuate enough to cause some trouble in this way.

---

3. Cause.—*Moisture in field coils.*

Symptom.—Field-circuit tests lower in resistance than normal in that type of machine, and in the case of shunt-wound machines the field takes more than the ordinary current. Field coils steam when hot, or feel moist to hand.

REMEDY.—Dry the field coils in a warm but not hot place. This may be done simply by passing a current through the field coils, which must be regulated so as not to exceed the usual field current.

Chapter V.

HEATING OF BEARINGS.

1. Cause.—*Lack of oil.*

Symptom.—Shaft and bearing look dry. Shaft usually turns stiffly. Oil cup or reservoir empty.

REMEDY.—Supply oil, and also make sure that oil passages as well as feeding or self-oiling devices work freely, and that the oil cannot leak out. This last fault sometimes causes oil to fail sooner than attendant expects.

---

2. Cause.—*Grit or other foreign matter in bearings.*

Symptom.—Best detected by removing shaft or bearing and examining both. Any grit can of course easily be felt, and will also scratch the shaft.

Fig. 5.—Shaft Rough or Cut.

REMEDY.—Remove shaft or bearing, clean both very carefully and see that no grit can get in. Place machine in dustless place or box it in.

---

3. Cause.—*Shaft rough or cut.* (Fig. 5.)

Symptom.—Shaft will show grooves or roughness, and will probably revolve stiffly.

REMEDY.—Turn shaft in lathe or smoothe with fine file and see that bearing is smooth and fits shaft.

4. Cause.—*Shaft and bearing fit too tight.*

Symptom.—Shaft hard to revolve by hand.

REMEDY.—Turn or file down shaft in lathe, or scrape or ream out bearings.

---

5. Cause.—*Shaft "sprung" or bent.*

Symptom.—Shaft hard to revolve and usually sticks much more in one part of revolution than in another.

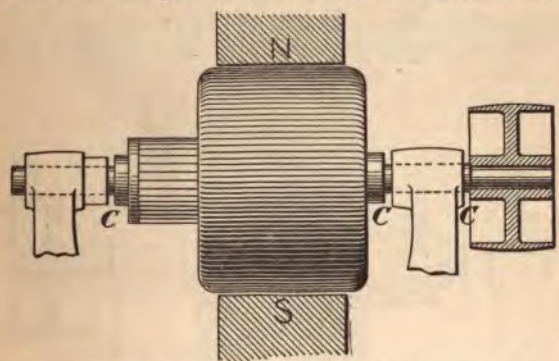

FIG. 6.—ARMATURE WITH GOOD CLEARANCE AT C C.

REMEDY.—It is almost impossible to straighten a bent shaft. It might be bent or turned true, but probably a new shaft will be necessary.

---

6. Cause.—*Bearings out of line.*

Symptom.—Shaft hard to revolve, but is much relieved by loosening screws which hold bearings in place. Bearing sometimes moves perceptibly when loosened, even when motor is not running, and belt is off.

REMEDY.—Loosen bearings by partly unscrewing bolts or screws holding them in place, and find their easy

and true position, which may either require it to be moved sideways or up and down ; then file the screw-holes of the bearings or raise or lower the bearings, as may be necessary, to make them occupy right position when screws are tightened.

---

7. Cause.—*Thrust or pressure of pulley, collar or shoulder on shaft against one or both of the bearings.* (Figs. 6 and 7.)

Symptom.—Move shaft, while revolving, back and forth with the finger or a stick applied to the end, and note

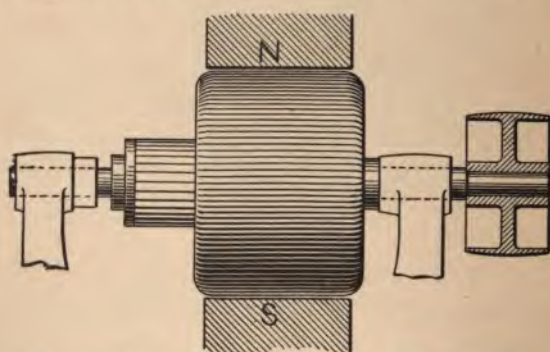

FIG. 7.—ARMATURE FORCED AGAINST BEARING.

if collar or shoulder tends to be pushed or drawn against either bearing. A dynamo or motor shaft should always be capable of moving freely back and forth a sixteenth or eighth of an inch to make commutator and bearings wear smooth (See Sparking, No. 3). If this does not occur it should be relieved in one of the following ways:

REMEDY.—Line up the belt, shift collar or pulley, turn off shoulder on shaft or file off bearing until the

shoulder does not touch when running or until pressure is relieved.

---

8. Cause.—*Too great load or strain on the belt.*

Symptom.—Great tension on belt. In this case pulley bearing will probably be very much hotter than the other and also worn elliptical, as indicated in Fig. 8, in which case the shaft may be shaken in the bearing in the direction of the belt pull, provided the machine has been running long enough to wear the bearings.

FIG. 8.—BEARING WORN ELLIPTICAL.

REMEDY.—Reduce load or belt tension, or use larger pulleys and lighter belt or even gearing so as to relieve side strain on shaft.

---

9. Cause.—*Armature too near one pole-piece, producing much greater magnetic attraction on nearer side.*

Symptom.—Examine the clearance of armature and see if it is uniform on all sides. Charge and discharge the field magnet, the armature being disconnected (by putting paper under one brush), and see if armature seems to be drawn to one side and turns very much less easily when field is magnetized.

REMEDY.—This fault is due to an inherent defect in the original construction, which is difficult to correct, but in cases of necessity the armature can be centered exactly in the field by moving the bearings, which may be done by carefully filing the holes through which the screws pass that hold the bearings in place, or the pole-piece may be filed away where it is too near the armature. It is sometimes possible to spring the pole-piece further away from the armature, but it is difficult and dangerous to attempt.

Chapter VI.

NOISE.

1. Cause.— *Vibration due to armature or pulley being out of balance.*

Symptom.—Strong vibration felt when hand is placed on machine while running. Vibration changes greatly if

Fig. 9.—Method of Balancing Armature.

speed is changed, and sometimes almost disappears at certain speeds.

REMEDY.—Armature or pulley must be perfectly balanced by securely attaching lead or other weight on light side, which can be found by trial. The easiest method of finding in which direction the armature is out of balance is to take it out and rest the shaft on two parallel and horizontal A-shaped metallic tracks sufficiently far apart to allow armature to go between them (Fig. 9). If the armature is then slowly rolled back and forth, the heavy side will, of course, tend to turn downward. The armature and pulley should always be balanced separately. An excess of weight

on one side of pulley and an equal excess of weight on opposite side of armature will not produce a balance while running, though it may appear to when standing still; on the contrary, it will give the shaft a strong tendency to "wobble." A perfect balance is only obtained when the weights are directly opposite, *i. e.*, in the same line perpendicular to the shaft.

---

2. Cause.—*Armature strikes pole-pieces.*

Symptom.—Easily detected by placing the ear near the pole-pieces or by examining armature to see if its surface is abraided at any point, or by examining each part of the space between armature and field, as armature is slowly revolved, to see if at any point it touches or is so close as to be likely to touch when the machine is running. It is unwise to have a clearance of less than one-sixteenth inch full. Also turn armature by hand when no current is on and note if it sticks at any point.

REMEDY.—Bind down any wire or other part of armature that may project abnormally, or file out pole-pieces where armature strikes.

---

3. Cause.—*Shaft collars or shoulders, hub or edges of pulley or belt rattling against bearings.*

Symptom.—Noise stops when shaft or pulley is pushed lengthwise away from one or the other of the bearings. (See Heating of the Bearings, No. 7.)

REMEDY.—Shift collar or pulley, turn off shoulder on shaft, file or turn off the bearing, move pulley on shaft or straighten belt until they do not strike and noise ceases.

4. Cause.—*Rattling due to looseness of screws or other parts.*

Symptom.—Close examination of the bearings, shaft, pulley, screws, nuts, binding-posts, &c., or touching the machine while running, or shaking its parts while standing still, will usually show the particular parts which are loose.

REMEDY.—Tighten up the loose parts, and be careful to keep them all in place and properly set up. It is very easy to guard against the occurrence of this trouble, which is very common, by simply examining the various screws and other parts each day before the machine is started.

---

5. Cause.—*Singing or hissing of brushes on commutator*, usually occasioned by rough or eccentric commutator (see Sparking at Commutator, No. 3), or by tips of brushes not being smooth, or the layers of a copper brush not being held together and in place; with carbon brushes, hissing will be caused by the use of carbon which is gritty or too hard. Vertical carbon brushes or inclined brushes running backward are apt to squeak or sing.

Symptom.—Sound of high pitch and easily located by putting the ear near the commutator while it is running, and by lifting off the brushes one at a time.

REMEDY.—Apply a very little oil to the commutator with the finger or a rag. Adjust brushes or smooth commutator by turning, filing or fine sandpaper, being careful to clean thoroughly afterwards. Carbon brushes are apt to squeak in starting up or at slow speed. This decreases at full speed, and can usually be reduced by moistening carbon brush with oil, care being taken not to have any drops or excess of oil. Shortening or lengthening the brushes sometimes stops the noise.

6. Cause.—*Flapping or pounding of belt joint or lacing against pulley.* (Fig. 10.)

Symptom.—Sound repeated once for each complete revolution of the belt, which is much less frequent than any other dynamo or motor sound, and can be seen or easily counted.

REMEDY.—Endless belt or smoother joint in belt. A perfect joint and a straight, smooth belt are always very desirable for dynamos and motors.

---

7. Cause.—*Slipping of belt on pulley due to overload.*

Symptom.—Intermittent squeaking noise.

FIG. 10.—BAD JOINTS IN BELT.

REMEDY.—Tighten the belt, or reduce the load. A wider belt may be required.

---

8. Cause.—*Humming of armature core teeth (if any) as they pass pole-pieces.*

Symptom.—Pure humming sound less metallic than No. 5.

REMEDY.—Slope ends of pole-pieces so that armature tooth does not pass edge of pole-piece all at once. Decrease the magnetization of the fields. Increase the cross-section or magnetic capacity of the teeth, or reduce that of the body of the armature, which is a matter of first construction.

Chapter VII.

SPEED TOO HIGH OR LOW.

This kind of trouble in either dynamo or motor is a serious matter, and it is always desirable, and generally imperative, to shut off the current immediately and make a careful investigation of the trouble.

---

1. Cause.—*Overload.* (See Sparking, No. 1.)

Symptom.—Armature runs more slowly than usual. Bad sparking at commutator. Ammeter indicates excessive current. Armature and bearings heat. Belt very tight on tension side.

REMEDY.—Reduce the load on machine by taking off lamps in the case of a dynamo, or mechanical work in the case of a motor; decrease the diameter of driving pulley or increase the diameter of driven pulley.

---

2. Cause.—*Short circuit in armature.*

Symptom and remedy the same as Heating of Armature, No. 2.

---

3. Cause.—*Armature runs slowly because it strikes pole-pieces.* Symptom and Remedy the same as Noise, No. 2.

---

4. Cause.—*Armature runs slowly because its shaft does not revolve freely in the bearings.*

Symptom.—Armature turns hard by hand; bearings and shaft heat when running.

REMEDY.—Oil the bearings; clean and smooth, if necessary, the shaft and bearings; line up the bearings. See Heating of Bearings, all cases.

---

5. Cause.—*Field magnetism weak.*

This has the effect of making a motor run too fast or too slow, or in some cases even run backwards, but makes a dynamo fail to "build up" or excite its field and give the proper voltage.

Symptom and Remedy the same as Sparking, No. 7. (See the following class; also, Dynamo Fails to Generate.)

Chapter VIII.

MOTOR STOPS OR FAILS TO START.

This trouble is, of course, an extreme case of the previous class (Speed too High or Low), but it is made a separate class because it is so perfectly definite and requires somewhat different treatment. This heading does not, of course, apply to dynamos, since they are usually driven positively by an engine and do not, like a motor, depend on their own operation for their motion.

1. Cause.—*Great Overload.* (See Sparking, No. 1.) A slight overload causes motor to run slowly, but an extreme overload will, of course, stop it entirely or "stall" it.

Symptom.—On a constant-current circuit no harm results, and motor starts properly when load is reduced or taken off.

On a constant-potential circuit the current is very excessive, and safety fuse melts, or, in the absence or failure of the latter to act, armature would be burnt out.

REMEDY.—Turn off switch instantly, reduce or take off the load, replace the fuse or cut-out if necessary, and turn on current again, just long enough to see if trouble still exists.

---

2. Cause.—*Very excessive friction due to shaft, bearings or other parts being jammed, or armature touching pole-pieces.*

Symptom.—Similar to previous case, but is distinguished from it by the fact that armature is hard to turn

by hand, even when load is taken off. Examination shows that shaft is too large, bent or rough, or bearing too tight, armature touches pole-pieces or other impediment to free rotation. (See Heating of Bearings and Noise.)

REMEDY.—Turn current off instantly, ascertain and remove cause of friction, turn on current again just long enough to see if trouble still exists.

---

3. Cause.—*Circuit open* due to (*a*) safety fuse melted, (*b*) wire in motor broken or slipped out of connections, (*c*) brushes not in contact with commutator, (*d*) switch open, (*e*) circuit supplying motor open, (*f*) failure at generating station.

Symptom.—Distinguished from Nos. 1 and 2 by the fact that if load is taken off motor still refuses to start, and yet armature turns freely by hand.

On a constant current-circuit the switch arcs badly when turned on if motor circuit is open; but there is no current, motion or other effect in motor. On a constant-potential circuit, field circuit alone of a shunt motor may be open, in which case pole pieces are not strongly magnetic when tested with a piece of iron; if armature circuit is at fault there is no spark when brushes are lifted, and if both are without current there is no spark when switch is opened.

REMEDY.—Turn current off instantly. Examine safety fuse, wires, brushes, switch and circuit generally for break or fault. If none can be found turn on switch again for a moment, as the trouble may have been due to a temporary stoppage of the current at the station or on the line. If motor still seems dead, test separately armature, field coils and other parts of circuit for continuity with a magneto or cell of battery and electric bell. (See Instructions for Testing.)

4. Cause.— *Wrong connection, or complete short circuit of field, armature or switch.*

Symptom.—Distinguished from Nos 1 and 2 in the same way as No. 3, and differs from No. 3 in the evidence of strong current in motor.

On a constant-potential circuit, if current is very great, it indicates a short circuit. If the field is at fault it will not be strongly magnetic.

The possible complications of wrong connections are so great that no exact rules can be given. Carefully examine and make sure of the correctness of all connections (see Diagrams of Connections). This trouble is usually inexcusable, since only a competent person should ever set up or change the connections of a motor.

Chapter IX.

DYNAMO FAILS TO GENERATE.

This class of troubles is, of course, confined to dynamos and corresponds somewhat to the previous class for motors. This trouble is almost always caused by the inability of the machine to sufficiently "excite" or "build up" its own field magnetism. The proper starting of a dynamo requires a certain amount of residual magnetism, which must be increased to full strength by the current generated in the machine itself.

---

1. Cause.—*Reversed residual magnetism*, due to (*a*) reversed current through field coils, (*b*) reversed connections, (*c*) earth's magnetism, (*d*) proximity of another dynamo, (*e*) brushes not in the right position.

Symptom.—Little or no magnetic attraction when pole-pieces are tested with piece of iron.

Magnetism weaker when machine is running and field circuit closed than when machine is stopped or field open, because current generated tends to build *down*, as it were, or neutralize the magnetism.

REMEDY.—Send a magnetizing current from another machine or battery through field coils, then start and try machine; if this fails, apply the current in the opposite direction and try machine again.

Reverse field and armature with respect to each other, *i. e.*, reverse connections of either one or shift brushes.

2. Cause.—*Too weak residual magnetism.* Symptoms and remedies of this trouble are substantially the same as in the previous case, but the attraction for a piece of iron is even weaker—in fact, practically nothing—when the machine is not running.

---

3. Cause.—*Short circuit in the machine or external circuit.*

This applies to a shunt-wound machine, and has the effect of preventing the voltage and the field magnetism from building up.

Symptom.—Magnetism weak, but still quite perceptible.

REMEDY.—If short circuit is in the external circuit, the opening of the latter will allow the dynamo to build up and generate full voltage. If the short circuit is within the machine, it should be found by careful inspection or testing. In either of these cases do not connect the external circuit till short circuit is found and corrected.

A slight short circuit, such as that caused by a defective lamp socket or copper dust on the commutator, may prevent magnetism from building up.

(See Sparking, Nos. 5 and 7.)

---

4. Cause.—*Field coils opposed to each other.*

Symptom.—If pole-pieces are approached with a compass or other freely suspended magnet, they both attract the same end of the magnet, showing them both to be of the same, instead of opposite, polarity.

For similar reasons the pole-pieces are quite strongly magnetic when tested separately with a piece of iron, but show less attraction when the same piece of iron is applied

to both pole-pieces at once, whereas the attraction should be much stronger. In multipolar machines these tests should be applied to consecutive pole-pieces.

REMEDY.—Reverse the connections of one of the coils, so that the polarity of the pole-pieces is opposite and not the same.

---

5. Cause.—*Open circuit.*

(*a*) Broken wire or faulty connection in machine, (*b*) brushes not in contact with commutator, (*c*) safety fuse melted or absent, (*d*) switch open, (*e*) external circuit open.

Symptom.—If the trouble is merely due to the switch or external circuit being open, the magnetism will be at full strength, and the machine itself may be working perfectly, but if the trouble is in the machine, the field magnetism will probably be very weak.

REMEDY.—Make very careful examination for opening in circuit; if not found, test separately the field coils, armature, etc., for continuity with magneto or cell of battery and electric bell. (See Instructions for Testing.)

CONCLUSION.

It is obviously difficult, if not impossible, in the treatment of dynamo and motor troubles to give complete directions for locating or identifying all the various troubles; but in most of the cases this will be found possible; and moreover, it is a fact that a mere list of these troubles, particularly if it is systematically arranged, is of the greatest help in overcoming these difficulties. It is in the promptness and intelligence which such troubles are dealt with that the ability or inability of a man is most clearly shown.

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